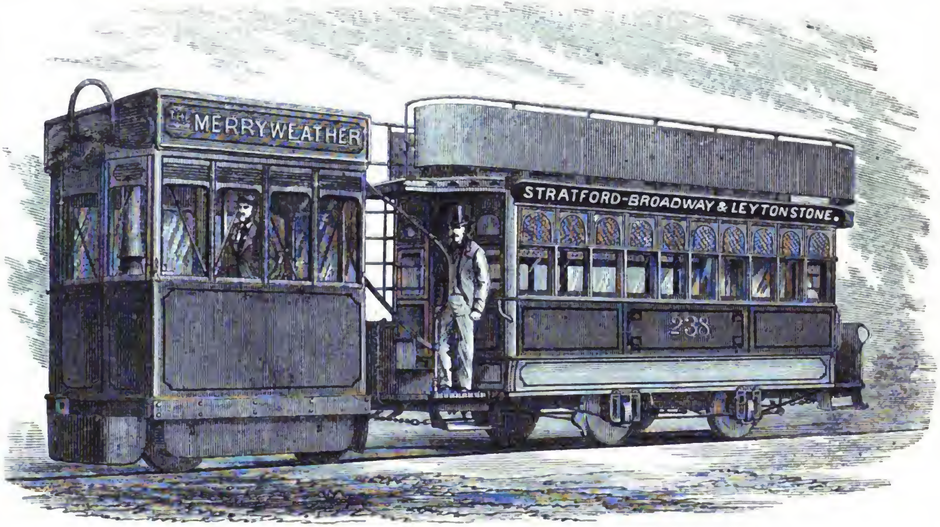
THE UNIVERSITY OF MICHIGAN · LIBRARIES ·



THE MERRYWEATHER TRAM-LOCOMOTIVE, WITH AN INSIDE-AND-OUTSIDE TRAM-CAR.

William W. Gollet

[illegible] 24. 1879

# TRAMWAYS

G. G. G.

## THEIR CONSTRUCTION AND WORKING

EMBRACING

A COMPREHENSIVE HISTORY OF THE SYSTEM, WITH AN
EXHAUSTIVE ANALYSIS OF THE VARIOUS MODES OF TRACTION,
INCLUDING HORSE POWER, STEAM, HEATED WATER, AND COMPRESSED
AIR; A DESCRIPTION OF THE VARIETIES OF ROLLING STOCK
AND AMPLE DETAILS OF COST AND WORKING EXPENSES

WITH SPECIAL REFERENCE TO THE

*TRAMWAYS OF THE UNITED KINGDOM*

BY

Daniel KINNEAR CLARK, C.E.

MEMBER OF THE INSTITUTION OF CIVIL ENGINEERS; AUTHOR OF
'RAILWAY MACHINERY' 'RAILWAY LOCOMOTIVES' ETC.

*WITH WOOD ENGRAVINGS AND FOLDING PLATES*

UNIVERSITY

LONDON
CROSBY LOCKWOOD AND CO.
7 STATIONERS'-HALL COURT, LUDGATE HILL
1878

*All rights reserved*

TF
705
.C59

Transp.
TF
705
.C59

LONDON: PRINTED BY
SPOTTISWOODE AND CO., NEW-STREET SQUARE
AND PARLIAMENT STREET

NU

Tramp. Lib.

# PREFACE.

TRAMWAYS have been developed by dint of sheer hard work and persistency, and they are now an accepted means of transport, urban and suburban, sanctioned by experience, approved and adopted by the public.

Unassuming and unobtrusive as they are, tramways have been the subject of a wide range of experience. By failures, engineers have discovered what would not do; and, as practical philosophers, they have, by induction, arrived at the conditions for efficiency. There exists a sentiment, which is somewhat prevalent, that tramway engineering is but a humble branch of the profession. The sentiment, born of self-complacency, is delusive. To tramways, it is true, Titanic arches, Acherontian tunnels, and Cyclopean engines, do not appertain. Nevertheless, tramways cost half as much as railways, and they earn more money by the mile; they have involved as much blundering as railways; like railways, they have exhausted reputations, and they have cost more than railways for working expenses.

The object of this book is mainly to place before engineers, capitalists, and financiers, a succinct analysis of the past practice and the present achievements in tramways in the United Kingdom, as works of engineering, and as money-making concerns. I have been materially aided in this work by the engineers of tramways, who have kindly placed their plans and specifications at my service; and by the secretaries and managers, who have supplied me with copies of their accounts.

I believe the results of these analyses will be found of essential service, in showing how the capital has been laid out, how the daily expenses are incurred, and in what directions economy of expenditure is to be effected.

Tramways will not take their fitting place in the systems of transport in the United Kingdom, until mechanical power is established in substitution for the power of horses. The employment of horse-power in the dire work of starting and dragging the ponderous cars in vogue, is an element of barbarism, germane, it may be, to the primitive habits of oriental life, but very much out of place in a civilised country.

D. K. CLARK.

8 BUCKINGHAM STREET, ADELPHI,
LONDON: *March*, 1878.

# CONTENTS.

## PART I.

## *ORIGIN AND PROGRESS OF TRAMWAYS.*

### CHAPTER I.

PAGES

INTRODUCTION OF TRAMWAYS.

Early timber tramways—Cast-iron tram-rails—Tramways in the United States—Cast-iron rail, by Mr. C. L. Light—Philadelphia step-rail—New York step-rail—Tramways in Buenos Ayres—Mr. G. F. Train's tramways in England; at Birkenhead, in London, in the Potteries—Mr. Haworth's tramway in Salford . . 1-18

### CHAPTER II.

MODERN TRAMWAYS IN THE UNITED KINGDOM.

The first Liverpool tramway—The crescent rail, by Mr. J. Noble—Act of Parliament for the Liverpool Tramways—Gauge of way—Construction—Gradients—North Metropolitan Tramways—Metropolitan Street Tramway—London Street Tramways—Length of tramways in the Metropolis—Number of Acts of Parliament obtained, 1868 to 1875—Total length of tramways at June 30, 1876—Table of tramways authorised and opened at June 30, 1876 . . . . . . . 19-29

### CHAPTER III.

TRAMWAYS IN THE METROPOLIS—THE LEEDS TRAMWAYS.

Construction—Defects . . . . . . . . 30-36

## CHAPTER IV.

PAGES

THE GLASGOW CORPORATION TRAMWAYS.

Construction of tramways under the first contract—Adaptation of the gauge for railway waggons—Details of cost . . . . . . . . . . 37–47

## CHAPTER V.

LARSEN'S FASTENING—LONDON STREET TRAMWAYS—BELFAST TRAMWAYS.

Description of Larsen's rail and side-fastening—Application of it in the London Street Tramways and the Belfast Tramways . . . . . . . 48–53

## CHAPTER VI.

DUBLIN TRAMWAYS.

Mr. Hopkins's improved side-fastening—Construction and cost of the Dublin Tramways . . . . . 54–58

## CHAPTER VII.

THE VALE OF CLYDE TRAMWAYS.

Construction—Section of rail for carrying railway waggons . . . . . . . . . . 59–65

## CHAPTER VIII.

RECONSTRUCTION OF THE NORTH METROPOLITAN TRAMWAYS—PARTICULARS OF COST OF LONDON TRAMWAYS.

Method of reconstruction—Cost of the London Tramways—Inclines and curves of tramways in London . 66–70

## CHAPTER IX.

PAGES

IRON WAYS :—LIVESEY'S—COCKBURN-MUIR'S —KINCAID'S—DOWSON'S—SCHENK'S.

Mr. Livesey's ways at Buenos Ayres—Cost—Mr. Cockburn-Muir's block-sleeper system—Cost—Transverse strength of his rail—Messrs. Ransome, Deas, & Rapier's cast-iron way—Mr. Kincaid's way—Sheffield Tramways—Dewsbury, Batley, and Birstal Tramway—Bristol Tramway—Adelaide Tramways—Messrs. Dowson's way—Madras Tramways—Cost—Schenk's way—Cost . 71-90

---

# PART II.

## *PRESENT PRACTICE OF TRAMWAY CONSTRUCTION IN THE UNITED KINGDOM.*

---

## CHAPTER I.

EDINBURGH STREET TRAMWAYS, 1871-75.

Detailed description and particulars of cost . . 91-100

## CHAPTER II.

DUNDEE STREET TRAMWAYS, 1877.

Detailed description and particulars of cost . . 101-107

## CHAPTER III.

PAGES

GLASGOW CORPORATION TRAMWAYS, 1874-75—SYSTEM OF MESSRS. JOHNSTONES & RANKINE.

Detailed description and particulars of cost . . 108-116

## CHAPTER IV.

BRISTOL TRAMWAYS, LEICESTER TRAMWAYS, SALFORD TRAMWAYS—KINCAID'S SYSTEM, 1876-77.

Detailed descriptions and particulars of cost . . 117-126

## CHAPTER V.

SOUTHPORT TRAMWAYS, WIRRAL TRAMWAY—BELOE'S SYSTEM.

Detailed descriptions and particulars of cost—Mr. Beloe's new double-rail system . . . . . . . 127-135

## CHAPTER VI.

MANCHESTER CORPORATION TRAMWAYS—BARKER'S SYSTEM.

Scheme of the Manchester Corporation Tramways—Detailed description and cost—Mr. Barker's way for country lines of light traffic . . . . . . 136-142

## CHAPTER VII.

LIVERPOOL TRAMWAYS—DEACON'S SYSTEM, 1877.

Detailed description and particulars of cost of the Liverpool Tramways—The Inner Circle—Branch lines—Table of cost for different classes of way . . 143-154

## CHAPTER VIII.

PAGES

MR. ROBINSON SOUTTAR'S SYSTEM OF TRAMWAY.

Detailed description and particulars of cost . . 155-160

## CHAPTER IX.

HARBOUR TRAMWAYS.

Glasgow Harbour Tramway, on the system of Messrs. Ransome, Deas, & Rapier—Way for lighter traffic—Belfast Harbour Tramway—Mr. T. R. Salmond's way 161-168

## CHAPTER X.

SUPPLEMENTARY—ON FOREIGN TRAMWAYS.

Tramways in Paris—Loûbat's way—Way between Sèvres and Versailles—*Tramways Nord*—Schedule of prices for and cost of Paris tramways—*Tramways Sud*—Cost for working—Versailles Tramways, by M. Francq—Lille Tramways—Tramways in Belgium: in Brussels, at Liége, at Anvers, at Gand—Cost of tramways in Brussels—Constantinople Tramways—Cost—Moscow Tramways—Leipzig Tramways—Cassel Tramway—Lisbon Tramway—Wellington City Tramways, New Zealand . . . . . . . . 169-190

## CHAPTER XI.

GENERAL CONCLUSIONS ON THE DESIGN AND CONSTRUCTION OF TRAMWAYS . . . 191-210

# PART III.

## *GENERAL COST OF TRAMWAYS, AND THEIR WORKING EXPENDITURE.*

### CHAPTER I.

PAGES
NORTH METROPOLITAN TRAMWAYS, 1871-76 . 213–219

### CHAPTER II.

LONDON TRAMWAYS, 1871–76 . . . . . 220–227

### CHAPTER III.

LONDON STREET TRAMWAYS, 1872–1876 . . 228–231

### CHAPTER IV.

DUBLIN TRAMWAYS, 1872–76 . . . . . 232–237

### CHAPTER V.

TRAMWAYS OF GLASGOW AND THE VALE OF CLYDE, 1872–76 . . . . . . . 238–242

### CHAPTER VI.

EDINBURGH STREET TRAMWAYS, 1871–76 . . 243–246

## CHAPTER VII.

PAGES
TRAMWAYS AT LEEDS, SHEFFIELD, AND SOUTHPORT—PROVINCIAL TRAMWAYS . 247–252

## CHAPTER VIII.

DEWSBURY, BATLEY, AND BIRSTAL TRAMWAY . . . . . . . . . . 253–257

## CHAPTER IX.

THE LONDON GENERAL OMNIBUS COMPANY . 258–264

## CHAPTER X.

ANALYSIS OF THE CAPITAL COST OF ENGLISH TRAMWAYS . . . . . . 265–268

## CHAPTER XI.

SUMMARY RECEIPTS OF TRAMWAYS . . . . 269, 270

## CHAPTER XII.

GENERAL ANALYSIS OF THE WORKING EXPENDITURE OF TRAMWAYS . . . . 271–273

# PART IV.

## *TRAMWAY CARS.*

### CHAPTER I.

PAGES

HISTORICAL NOTICE OF TRAMWAY CARS.

Original tram-car, New York—Weight of cars constructed by the Starbuck Car and Waggon Company—Great strain on tramway cars—The fiction of 'dead-weight' . . . . . . . . . . 274–281

CHAPTER II.

INSIDE-AND-OUTSIDE PASSENGER-CAR, CONSTRUCTED BY THE METROPOLITAN RAILWAY CARRIAGE AND WAGGON COMPANY.

Detailed description—Wheels and axles—Axle-boxes—Load on journals—Leverage of the brake—Disc-wheels . . . . . . . . . 282–292

CHAPTER III.

INSIDE-PASSENGER CAR, CONSTRUCTED BY THE STARBUCK CAR AND WAGGON COMPANY.

Description—Leverage of the brake . . . . 293, 294

## CHAPTER IV.

PAGES

RADIAL-AXLE PASSENGER-CAR, BY MR. JAMES CLEMINSON.

Description of the 'flexible wheel-base' . . . . 295–299

## CHAPTER V.

BEARING-SPRINGS.

Messrs. George Spencer & Co.'s indiarubber springs—Deflection—'Rubber-centre spiral springs,' by Messrs. L. Sterne & Co.—Deflection . . . . . . 300–303

## CHAPTER VI.

CAR-WHEELS.

Cast-iron wheels—The Handyside wheel. . . . 304–305

## CHAPTER VII.

FRENCH TRAM-CARS.

Winter car, by M. Francq—Summer car, by M. Francq—Cars of the *Compagnie Générale des Omnibus* . 306–309

## CHAPTER VIII.

EADE'S REVERSIBLE CAR . . . . . . 310, 311

# PART V.

## *MECHANICAL POWER ON TRAMWAYS.*

### CHAPTER I.

PAGES

HISTORICAL SKETCH OF THE APPLICATION OF MECHANICAL POWER ON TRAMWAYS.

Latta—Grice & Long—Train—Todd's steam-locomotive—Lamm's ammoniacal-gas car—Lamm's hot-water locomotive—Hot-water locomotive on the East New York and Canartio line—Results of tests—Baxter's steam-car—Grantham's steam-car—Trials at West Brompton—On the Wantage tramway—Grantham car for the Vienna tramways—Trials on the Hoylake and Birkenhead tramway, and at Vienna—Perkins' tramway-locomotive on the Belgian Street railway—Three-cylinder steam-locomotive, by the *Société Métallurgique,* Belgium—Kohl's locomotive at Copenhagen—Smith & Mygind's locomotive at Copenhagen—Francq's hot-water locomotive in Paris—Todd's hot-water steam-car—Bède's hot-water steam-car in Belgium—Merryweather's steam-locomotive for the Paris tramways—Hughes' steam-locomotive at Leicester and at Glasgow—Baldwin locomotive—Baldwin steam-car—Its working cost—Cost of running horse-cars in Philadelphia—Ransom's steam-car . . . . . . . 312–348

### CHAPTER II.

ELEMENTARY DATA FOR MECHANICAL POWER.

Resistance to traction—Experiments by Mr. H. P. Holt—By Mr. Hughes—By M. Tresca—By Colonel de Sytenko — Conclusions on tractional resistance —

PAGES

Mechanical propulsion—Rules for tractive force—Effective mean pressure in the cylinders—Adhesion—Influence of gradients—Rules for quantity of steam consumed—Table of properties of saturated steam—Application of the rules—Data for consumption of fuel and water . . . . . . . . 349–365

## CHAPTER III.

### HOT-WATER TRAMWAY LOCOMOTIVES.

Properties of heated water—Cockerell's hot-water locomotive at Seraing—Results of experiments . . 366–374

## CHAPTER IV.

### COMPRESSED-AIR ENGINES.

Compression and expansion of air—Dr. Colladon's experiments at Airolo—M. Mallard's investigations—Compressed-air engines by Messrs. John Fowler & Co. —Compressed-air car by M. Mékarski, in Paris—Compressed-air car by Mr. Scott-Moncrieff—Compressed-air car by Major Beaumont. . . . 375–386

## CHAPTER V.

### TRAMWAY LOCOMOTIVES, BY MESSRS. MERRYWEATHER & SONS, LONDON.

Three classes of locomotives—Description and performance of engines on the Paris tramways—Engines on the Barcelona tramways—Engines for the tramways at Cassel, Rouen, Guernsey, and Wellington, New Zealand . . . . . . . . . . 387–394

## CHAPTER VI.

### AUXILIARY COMPOUND INCLINE-LOCOMOTIVE FOR TRAMWAYS, BY MR. HENRY P. HOLT.

Description of the peculiar features of the engine . 395–398

## CHAPTER VII.

PAGES

TRAMWAY CONDENSING LOCOMOTIVE, BY MR. LOFTUS PERKINS.

Description of the engine—Water-tube boiler—Three cylinders—Expansive Working—Condensers . . 399–402

## CHAPTER VIII.

BISSELL-BOGIE STEAM-CAR, BY MR. EDWARD PERRETT.

Steering gear—Results of experiment . . . 403–405

## CHAPTER IX.

DOUBLE-BOGIE STEAM-CAR, BY MR. A. BROWN.

Dimensions and performance on the Lausanne and Echellens Branch railway . . . . . . 406–410

## CHAPTER X.

DOUBLE-BOGIE STEAM-CAR, BY MR. W. R. ROWAN.

Description and particulars of performance . . 411–414

*CONCLUSION* . . . . . . . 415–419

*APPENDIX—TRAMWAY LEGISLATION* . 420–426

*INDEX* . . . . . . . . . . 427

# LIST OF PLATES.

PLATE PAGE

I.—EDINBURGH STREET TRAMWAYS . . . . . 91

DUNDEE STREET TRAMWAYS . . . . . 101

II.—GLASGOW CORPORATION TRAMWAYS . . . 108

III.—BRISTOL TRAMWAYS—KINCAID'S SYSTEM . . . 117

IV.—SOUTHPORT TRAMWAYS . . . . . 127

WIRRAL TRAMWAY . . . . . . . . 130

V.—MANCHESTER CORPORATION TRAMWAYS—BARKER'S SYSTEM . . . . . . . . . . 136

VI.—LIVERPOOL TRAMWAYS—DEACON'S SYSTEMS . . 143

VII.—INSIDE-AND-OUTSIDE PASSENGER-CAR, BY THE METROPOLITAN RAILWAY CARRIAGE AND WAGGON COMPANY . . . . . . . . . 282

VIII.—INSIDE PASSENGER-CAR, BY THE STARBUCK CAR AND WAGGON COMPANY . . . . . 293

IX.—FRENCH TRAM-CAR . . . . . . . 306

X.—TRAMWAY LOCOMOTIVE, BY MESSRS. MERRYWEATHER & SONS (cylinders 7 in. by 11 in.) 387, 390

XI.—TRAMWAY LOCOMOTIVE, BY MESSRS. MERRYWEATHER & SONS (cylinders 6 in. by 9 in.) . 391

XII.—AUXILIARY COMPOUND INCLINE-LOCOMOTIVE, BY MR. HENRY P. HOLT . . . . . . 395

XIII.—CONDENSING STEAM-LOCOMOTIVE, BY MR. LOFTUS PERKINS . . . . . . . . . 399

# LIST OF WOOD ENGRAVINGS.

FIG. PAGE

1. EARLY TIMBER TRAMWAYS . . . . . . . 3
2. DO. DO. WITH DOUBLE RAILS . . . 3
3. CAST-IRON TRAMWAY-RAILS, BY THE COLEBROOKE DALE IRON COMPANY . . . . . . . . 5

4 to 9. NEW YORK TRAM-RAILS . . . . . . 7, 8

10. CAST-IRON RAIL, BY MR. C. L. LIGHT . . . . 10
11. PHILADELPHIA STEP-RAIL . . . . . . . 11

12, 13. PHILADELPHIA TRAMWAYS . . . . . . 12

14. NEW YORK STEP-RAIL . . . . . . . . 13

15, 16. TRAIN'S TRAMWAY AT BIRKENHEAD . . . . 16

17. CRESCENT RAIL, BY MR. J. NOBLE . . . . . 19
18. EARLY LIVERPOOL RAIL . . . . . . . . 22

19 to 21. FIRST LIVERPOOL TRAMWAY . . . . 23, 24

22. NORTH METROPOLITAN TRAMWAY, AND LONDON TRAMWAYS . . . . . . . . . . 30
23. PIMLICO, PECKHAM, AND GREENWICH SECTION OF LONDON TRAMWAYS . . . . . . . . 33
24. SECTION OF RAIL, LONDON TRAMWAYS . . . . 34
25. GLASGOW CORPORATION TRAMWAYS—FIRST SYSTEM . 38
26. LARSEN'S SIDE-FASTENING . . . . . . . 48
27. DO. DO. FOR THE LONDON STREET TRAMWAYS . 50
28. LONDON STREET TRAMWAYS . . . . . . . 51
29. BELFAST TRAMWAYS—SECTION OF RAIL, WITH LARSEN'S FASTENING . . . . . . . . 51

FIG. PAGE

30, 31. DUBLIN TRAMWAYS . . . . . . 55, 56

32. VALE OF CLYDE TRAMWAYS—SECTION OF RAIL . . 60

33. NORTH METROPOLITAN TRAMWAYS—METHOD OF RECONSTRUCTION . . . . . . . . 67

34 to 36. BUENOS AYRES TRAMWAYS—LIVESEY'S STEEL-RAIL SYSTEM . . . . . . . . 71, 72

37. BUENOS AYRES TRAMWAYS — LIVESEY'S IRON-RAIL SYSTEM . . . . . . . . . 74

38 to 40. COCKBURN-MUIR'S IRON WAY AT MONTE VIDEO, &c. . . . . . . . . . 76, 77

41 to 43. KINCAID'S IRON WAY . . . . . 80, 81

44. DOWSON'S IRON WAY—MADRAS TRAMWAYS . . . 84

45 to 47. DOWSON'S IMPROVED IRON WAY . . . 85, 86

48. SCHENK'S IRON WAY . . . . . . . 88

49 to 51. SALFORD CORPORATION TRAMWAYS—KINCAID'S SYSTEM, MODIFIED BY MR. A. M. FOWLER . 122, 123

52 to 56. NEW DOUBLE-RAIL SYSTEM, BY MR. C. H. BELOE . . . . . . . . 133, 134, 135

57. BARKER'S SYSTEM OF WAY, FOR LIGHT TRAFFIC . . 142

58 to 61. MR. ROBINSON SOUTTAR'S SYSTEM OF TRAMWAY . . . . . . . . 155, 156, 157

62, 63. GLASGOW HARBOUR TRAMWAY — SYSTEM OF MESSRS. RANSOME, DEAS, & RAPIER . . . 161, 162

64. SYSTEM OF MESSRS. RANSOME, DEAS, & RAPIER FOR LIGHTER TRAFFIC, &C. . . . . . . . . 164

65. BELFAST HARBOUR TRAMWAY—LIZARS' SYSTEM . . 165

66, 67. DO. DO. SALMOND'S SYSTEM . 166, 167

68, 69. LOUBAT'S SYSTEM . . . . . . . . 169

70 to 74. SECTION OF RAILS IN TRAMWAYS OF PARIS 170, 171, 174

75 to 77. VERSAILLES TRAMWAYS . . . . . . 176

78, 79. LILLE TRAMWAYS . . . . . . . . 178

80 to 86, 88. SECTION OF RAILS OF TRAMWAYS IN BRUSSELS . . . . . . . . 180, 181, 182

87. SECTION OF RAIL OF TRAMWAY AT ANVERS . . 181

FIG. PAGE
89. SECTION OF RAIL AND TYRE OF WHEELS, FOR LIÈGE TRAMWAYS . . . . . . . . . . 182
90. SECTION OF RAIL, GAND TRAMWAY . . . . . 182
91 to 93. TRAMWAYS AT CONSTANTINOPLE . . . . . 184
94, 95. MOSCOW TRAMWAYS . . . . . . . . 186
96, 97. LEIPZIG TRAMWAYS . . . . . . . . 187
98. CASSEL TRAMWAY—SECTION OF RAIL AND WHEEL-TYRE . . . . . . . . . . 188
99. WELLINGTON CITY TRAMWAYS . . . . . . . 190
100. ORIGINAL TRAM-CAR, NEW YORK . . . . . 274
101 to 103. DUBLIN PASSENGER-CAR—WHEELS AND AXLE 284, 285, 286
104, 105. DO. DO. AXLE-BOX . . . . . 287
106, 107. DISC CAR-WHEEL AND AXLE . . . . . . 291
108. STARBUCK CAR.—SECTION OF WHEEL-TYRE . . 293
109 to 111. MR. CLEMINSON'S SYSTEM OF RADIATING AXLES . . . . . . . . 296, 297, 298
112. THE HANDYSIDE CAR-WHEEL . . . . . . 305
113. STEAM-LOCOMOTIVE, BY MR. L. J. TODD . . . 315
114. AMMONIACAL-GAS CAR, BY DR. LAMM . . . . 316
115. HOT-WATER LOCOMOTIVE, BY DR. LAMM . . . 317
116. STEAM-CAR, BY MR. BAXTER . . . . . . 322
117. STEAM-CAR, BY MR. JOHN GRANTHAM . . . . 323
118. DO. DO. . . . . . . . . 326
119, 120. HOT-WATER STEAM-CAR, BY MR. L. J. TODD . 335
121, 122. BISSELL-BOGIE STEAM-CAR, BY MR. EDWARD PERRETT . . . . . . . . . . 404, 405
123, 124. DOUBLE-BOGIE STEAM-CAR, BY MR. A. BROWN . 407
125. DOUBLE-BOGIE STEAM-CAR, BY MR. W. R. ROWAN . 411

# TRAMWAYS.

## PART I.

## *ORIGIN AND PROGRESS OF TRAMWAYS.*

## CHAPTER I.

### INTRODUCTION OF TRAMWAYS.

A TRAM, according to Nuttall, is the shaft of a cart or carriage. It is also the local name of a coal-waggon, whence is derived the compound word *tramway* or tramroad—a road laid with narrow tracks of wood, stone, or iron, for trams or waggons.

In France, tramways were officially known as 'horse-railways' (*voies ferrées à traction de chevaux*). By the public they were known as 'American railways' (*chemins de fer Américains*, or simply *l'Américain*). Finally, of late, the English word 'tramway' has become universally adopted in France.

A tramway, in the modern sense of the word, is a street-railway or a road-railway, constituting, with the carriage-way, a combination of railways and common thoroughfares: such that the traffic of the

66

street or the road, unaffected by the tramway, is free to circulate. It follows, as the principal condition of such free circulation, that the surface of the rails, whilst they are adapted for carrying flanged wheels, should be substantially at the general level of the carriage-way.

Tramways, for facilitating heavy continuous traffic, were, as may be imagined, more desirable in the days of no roads or bad roads, than they are even now. They were laid, more than two hundred years ago, in the mineral districts of England, when coal was rapidly supplanting wood as fuel, for the conveyance of coal to the sea-coast for shipment. The difficulty of keeping the roads in repair—leading from coal-mines—may easily be conceived. Something of the condition of roads in the ante-macadam period may be witnessed to-day in the earth roads of Egypt. These, after a heavy fall of rain, become seas of mud, and constitute formidable impediments to circulation, instead of facilitating it. Our forefathers were led to lay planks or timbers at the bottoms of the ruts, as a better contrivance than filling in stones. The inconvenience of the ruts, again, led to placing planks or rails of timber on the level surface. In 1676, tramways consisted of rails of timber laid 'from the colliery to the river, exactly straight and parallel.'

The rails originally were formed of scantlings of good sound oak, and were connected by sills or cross-timbers of the same material, pinned together with oak trenails, as shown in fig. 1. The rails were 4 inches deep, and 4 or 5 inches wide, laid parallel, 3 or 4 feet apart, in lengths of 6 feet. The cross-sleepers were 6 feet long by 4 or 5 inches deep, and

5 inches wide, laid about 2 feet apart between centres. The rapid abrasion and wear of the rails, in consequence of the coarse construction of the wheels, and the wear of the sleepers by the action of the horses' feet, led to the placing of an additional rail, fig. 2, upon the first rail. This second rail became the wearing piece, and could be renewed with facility; whilst the increased depth afforded by it admitted of the covering of the sleepers by the soil, and their protection from the horses' feet. The wearing rails were of hard wood — beech or sycamore — 6 feet long by from 4 to 6 inches deep. The under rails of the double way, at first made of oak, were subsequently made of fir.

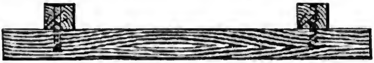


FIG. 1. Early timber tramways. Scale, $\frac{1}{24}$.

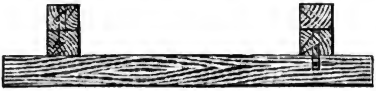


FIG. 2. Early timber tramways, with double rails. Scale $\frac{1}{24}$.

It became a common practice to nail down bars of wrought iron on the surface of the ascending inclines of the road, where the draught was increased, in consequence of the greater wear of the timber. These bars, or rails, were about 2 inches wide, and $\frac{1}{2}$ inch thick, and fastened to the wood rails by nails having countersunk heads. But the iron bars, not being stiff enough, were considerably bent when the trucks were loaded, and the resistance, according to Mr. Wood, was reduced but slightly below that of a well-constructed double wooden railway.

Nevertheless, a marked improvement in the performance of the draught-horses followed upon the establishment of the tramway. The regular load of coals for one horse, on the common road, amounted to 8 bolls or 17 cwt., whilst, upon the tramway, the horse could regularly take a load of 19 bolls or 42 cwt. of coal.

Cast-iron was first tried incidentally, as a material for rails, in 1767, by the Colebrooke Dale Iron Company, who determined to protect their oak rails with cast-iron, 'not altogether as a necessary expedient of improvement,' says Mr. Hornblower, writing in 1809, 'but in part as a well-digested measure of economy in support of their trade. From some adventitious circumstances, the price of pigs became very low, and their works being of great extent, in order to keep the furnaces in, they thought it would be the best means of stocking their pigs to lay them on the wooden railways, as it would help to pay the interest by reducing the repairs of the rails; and if iron should take any sudden rise, there was nothing to do but to take them up, and to send them away as pigs.'[1]

The iron rails were cast in lengths of 5 feet, 4 inches wide, and 1¼ inches thick, as in fig. 3, formed with three holes, through which they were fastened to the oak rails; 'and very complete it was, both in design and in execution.' See fig. 3.

The tramway was developed into the railway by the employment of flange-rails and edge-rails of cast-iron and of wrought-iron, designedly elevated above the surface of the ground, upon new tracks laid out specifically for the formation of railways. But, a reaction set in when it was found that railways wanted the needful adaptability to follow out the subordinate lines of traffic which occupied roads and streets. The convenient and unpretentious tramway was revived, and laid in streets and common roads, for the conveyance of passengers on the omnibus system. The revivals have, for the most part, been, like the primitive tramways, worked by the power of horses. Nevertheless, in view of the success of the tramway system, as a mechanical fact, it may be expected that

---

[1] *Observations by Mr. Hornblower*, in the *Appendix to the Third Report of the Committee on Highways*, 1809.

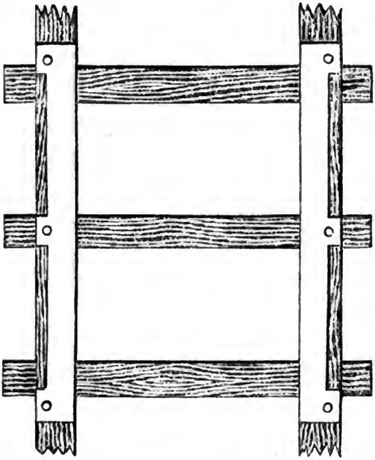


FIG. 3. Cast-iron tram-rails, by the Colebrooke Dale Iron Company. Scale $\frac{1}{24}$.

steam or other mechanical power will be substituted for horses.

The modern tramway was first employed in the United States, where it was urgently wanted, in consequence of the inferior condition of the streets and roads of the large cities. The first American tramway was the New York and Haarlem line, of which the first section, laid in the main thoroughfares, was opened in 1832. It was laid to a gauge of 4 feet 8½ inches. But it was unpopular, and was for a time suppressed. Tramways, nevertheless, were revived in the same city, about the year 1852, by the instrumentality of M. Loûbat, a French engineer, who recommended and laid down a tramway, consisting of rolled wrought-iron rails laid upon wooden sleepers. The rails were constructed with a groove in the upper surface, to guide the wheels of the cars, which were made with flanges, like those of railway carriages and waggons.[1] Tramways were rapidly multiplied in New York, which owes much of its development to the tramways, the traffic upon which is of much more importance than that of the light-wheeled vehicles, used for ordinary circulation. Otherwise the rails, which were formed with wide, gulf-like grooves, would not have been tolerated in the streets. The tramway afforded incalculable advantages, and it became an indispensable feature in the principal cities of the United States. The long distances to be traversed, the generally bad condition of the streets and roads, and the comparative scarcity of other vehicles, formed a combination of circumstances which forced the tramway-car into general use for all classes.

---

[1] The rails laid by M. Loûbat, in Paris, hereafter noticed, were similar to those laid by him in America.

NEW YORK TRAM-RAILS. Scale, ½ full size.

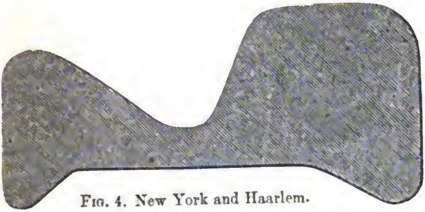


FIG. 4. New York and Haarlem.

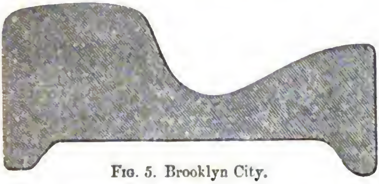


FIG. 5. Brooklyn City.

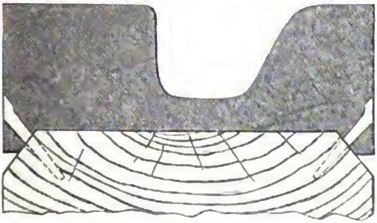


FIG. 6. New York, Second Avenue.

Habits were formed, and the irregularities of rails and roads were of less importance than they had been felt to be in this country. The annexed sectional illustrations show the fearless manner in which the New York tram-rails were proportioned—combining

New York Tram-Rails. Scale, ½ full size.

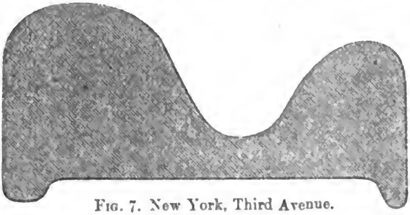


Fig. 7. New York, Third Avenue.

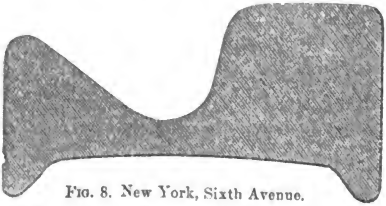


Fig. 8. New York, Sixth Avenue.

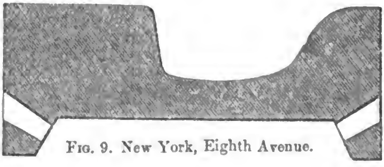


Fig. 9. New York, Eighth Avenue.

obnoxious grooves with massive sections. An unsophisticated observer, struck by the proportions of the rails in New York, with the portentous grooves, described them as 'rails which have a sort of iron gutter attached to each on their inside edge.'[1]

TRAM-RAILS IN NEW YORK.

| Fig. | TRAM-RAILS | Weight per yard | Depth of groove | Depth at head | Total width |
|---|---|---|---|---|---|
| | | lb. | inch | inches | inches |
| 4 | New York and Haarlem . | 98 | $1\frac{5}{8}$ | $2\frac{1}{4}$ | $5\frac{3}{4}$ |
| 5 | Brooklyn City . . . | 67 | $1\frac{1}{4}$ | $1\frac{13}{16}$ | $4\frac{7}{8}$ |
| 6 | New York, Second Avenue | 69 | $1\frac{1}{4}$ | $1\frac{11}{16}$ | 5 |
| 7 | " Third Avenue . | 90 | $1\frac{3}{4}$ | $2\frac{1}{8}$ | $5\frac{3}{8}$ |
| 8 | " Sixth Avenue . | 76 | $1\frac{5}{8}$ | $2\frac{1}{8}$ | 5 |
| 9 | " Eighth Avenue | 61 | 1 | $1\frac{1}{2}$ | 5 |

---

[1] Letter of Mr. Longley, quoted by Mr. Beresford Hope, in his evidence before the Select Committee on Tramways, 1872. Mr. Peel, a member of the Committee, struck by the originality of the notion of a 'gutter' alongside the rail, naturally inquired of Mr. Hope,—

In comparing the New York system with that adopted in London, you spoke of an iron gutter as being a feature of the system?

*Ans.* My correspondent is Mr. Longley, son of the late Archbishop, who is very well known, and who happened to be in New York last year. I do not know whether you wish to challenge the social condition of my New York correspondent.

Not by any means. But, as I understand, the iron gutter is not at all used in the English system?

*Ans.* I do not suppose that any witness has contended that it is.

But when you say that the New York system is characterised by iron gutters, and is therefore disadvantageous to the public, what is the inference you wish the Committee to draw?

*Ans.* That the New York system has one more element of inconvenience in it than the English system.

As Mr. Hope himself said in his next answer, such sort of evidence is 'a mere red herring, very unfair and very untrue.' Of

Mr. Charles L. Light, an English engineer, properly conceiving that the great groove, or 'gutter,' in the rail, was a great nuisance, devised and laid, in 1856–57, a less incommodious tram-rail in the streets of Boston, U.S., in which the depth of the groove was limited to ¾ inch, whilst the inner side of the groove was carried up with a flat slope, so formed that mud or small stones could be the more readily pushed away by the flanges of the car-wheels. The groove was not so deep, and not so damaging to the wheels of ordinary vehicles, as the grooves of the New York rails. The rails, fig. 10, were of cast-iron, in lengths of 6 feet and 8 feet, weighing 75 pounds per yard. The ends of the rails were formed with dowels and cores, placed diagonally, which, being interlocked, were designed to maintain the ends of

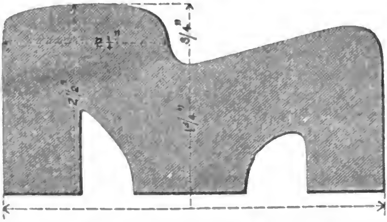


Fig. 10. Cast iron rail, Boston, U.S., by Mr. C. L. Light. Scale ½.

such is history made. Here is another bit of Mr. Hope's evidence: 'Omnibuses, dangerous and disagreeable as they are, move in and out; while a tramway cannot move in and out.' 'Mr. Train ran one of his lines, and had a station for his omnibuses under my window, and the noise, and the hallooing, and the row that went on was a great inconvenience, certainly.' Such evidence was unanswerable.

the lengths of rail at one level. These rails, after several years, were replaced by rails of wrought-iron.

To mitigate the inconveniences of the New York sections of tram-rail, a different form of rail—a 'step-rail,' as it may be called—fig. 11, from which the groove was banished, though a ridge remained, was introduced in Philadelphia, and laid in Fifth and Sixth Streets, where it gave satisfaction. It consisted of a flat plate, 5 inches wide, formed with a raised ledge or fillet at one edge, standing ⅞ inch above the surface of the plate, without any groove. The plate was formed with a ledge or fillet at each side, below, let into corresponding rebates in the upper corners of the sleepers.

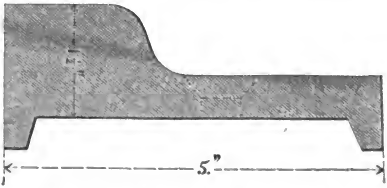
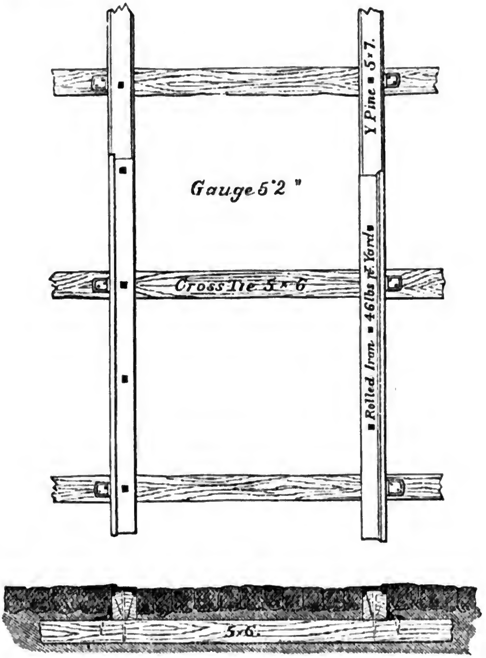


Fig. 11. Philadelphia step-rail. Scale ½.

The weight was 46 pounds per yard. The gauge was fixed at 5 feet 2 inches between the ledges to suit the wheels of ordinary vehicles, which could run on the lower flat surface. The type of tramway thus settled for Philadelphia, in 1855, which is still adhered to, is shown in figs. 12 and 13.

The rails were laid on longitudinal sleepers of yellow pine, 5 inches wide and 7 inches deep, bolted down upon transverse sleepers 6 inches wide and

5 inches deep, with iron knees to maintain the rails in gauge.



FIGS. 12 and 13. Philadelphia Tramways. Scale $\frac{1}{35}$.

Following the principle of the Philadelphia rail, but adopting a greater width—8 inches—a similar rail, fig. 14, was introduced in New York previous to

1860. It was better adapted for taking the wheels of ordinary vehicles, which varied considerably in gauge, whilst new vehicles of the ordinary kinds were made to fit the tramway.

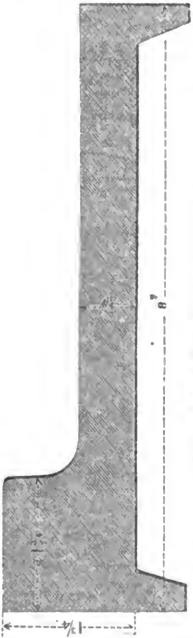


FIG. 14. New York step-rail. Scale ¼.

But, the wide tram-plate, or step-rail, incurs the objection that it does not afford a good foothold for horses, whether harnessed to tram-cars or to ordinary vehicles. There is, besides, the general objection to the step form of the surface, in which, though the rise may never exceed an inch, the elevation is sufficient to cause a considerable degree of inconvenience to vehicles crossing the rails in an oblique direction, in straining the wheels or the axles. The step-rail possesses, on the contrary, the advantage over the grooved rail, that the flange of the car-wheel is always free, as there is no groove for the lodgment of obstructive pebbles and mud, whilst there is nothing to seize the wheels of ordinary vehicles.

The step-rail is in general use in the principal cities of the United States, where probably there is less of the light cab and omnibus traffic than prevails in English cities, exposed to the action of the obnoxious step.

The step-rail is laid in the tramways of Washington, U.S., and it is probably the form of rail most generally adopted for tramways in the United States. Tramways have been widely extended in the chief cities of the Union. In the State of New York alone, in 1875, there were 87 street-railroad companies, comprising an aggregate length of 433 miles of tramway open for traffic.

The gauge of tramway rails adopted, for the most part, in the United States, is 4 feet 8½ inches.

The tramway system of Buenos Ayres, the principal city of the Argentine Republic, is a conspicuous example of the beneficial adoption of tramways in towns. There were, in 1872, in operation or in course of construction, about 70 miles of tramway in that city—a greater mileage, probably, in proportion to the size of the place, which contains 200,000 inhabitants, than has been laid in any other city in the world. The extraordinary development of the system there, is attributable in a great measure to the comfort, the cheapness, and the rapidity of tramway locomotion, compared with the previously existing means of conveyance in carriages or omnibuses over a very rough kind of paving. The town is built, like the towns and cities of the United States, in square blocks, the streets being straight, parallel, and at right angles to each other. Almost every street has its line of tramway, laid, for the most part, on Livesey's system, to be afterwards described. The principal lines are known as the City, the Billinghurst (now the Argentine), the Lacroze, the National, the Mendez, and the Southern Tramways. One particular feature which added to the cost of working these tramways was the necessity, some years ago, for having 'trumpeters'—men on horseback, who ride in advance of the cars, each blowing a trumpet to warn off carts and other vehicles from the track, as well as to prevent collisions at the intersections of the streets, and, further, to assist in dragging out of the way any heavily-laden or broken-down vehicle obstructing the line.[1]

The modern tramway was introduced in England by Mr. G. F. Train, who, in 1857, made proposals for laying tramways, on the system originated in Philadelphia, in some of the metropolitan thoroughfares and in a few provincial towns. Mr. Train associated with himself Mr. James Samuel, C.E., but they failed in their object of obtaining an Act of Parliament, which was applied for in 1858, mainly through the opposition of Sir Benjamin Hall, Chief Commissioner of Works. 'It was utterly impossible,' he said, 'that the iron rails or plates upon which the carriages were to run could be laid on macadamised roads, for instance, with a certainty of always being kept on precisely the same level as the road; and carriages running diagonally against the plates would be subjected to have their wheels torn off, and most serious accidents would result, whatever precautions might be taken. Even the weather would at times effect this.'[2]

'Sir Benjamin Hall,' says Mr. Train, 'did not meet the arguments of Mr. Samuel, except by prejudice. Arguing against facts is difficult, and over-riding stubborn truths impossible.' Sir Benjamin, nevertheless, was proved to be in the right.

---

[1] *Engineering*, May 17, 1872, page 332.

[2] *Observer*, February 21, 1858.

In default of better authority, Mr. Train, in March 1860, applied for, and in May of the same year obtained, permission from the Commissioners of Birkenhead to lay down his tramway in this town. In April he patented his system.

'The egg,' Mr. Train said, 'will shortly be chipped in this country under my patent, at great cost and labour, and I shall endeavour to prevent my chicken (as is too frequently the case with valuable inventions) from becoming somebody else's hen.'

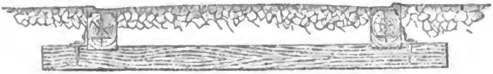


FIG. 15. G. F. Train's tramway at Birkenhead. Scale $\frac{1}{24}$.

So, the first of his lines was laid in the macadamised roads of Birkenhead, and was opened in August 1860, within five months after the application for leave was made. It is illustrated by figs. 15 and 16.

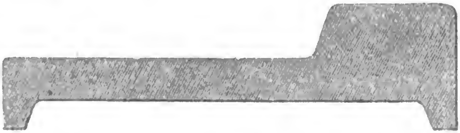


FIG. 16. G. F. Train's tramway at Birkenhead. Section of rail. Scale ½.

It has rolled wrought-iron step-rails, weighing about 50 pounds per yard, laid to a gauge of 4 feet 8½ inches. The rails were 6 inches wide and $\frac{9}{16}$ inch thick in the sole, with a step rising ¾ inch above the sole, and a fillet at each edge on the lower side. They were bedded on and spiked to longitudinal timber sleepers, 6 inches wide and 8 inches deep, which were let into and rested on transverse sleepers, and were spiked to them with one iron knee to each.

Short lines, similarly, were, by the permission of the local authorities, laid down in London by Mr. Train and his friends in 1861 :—in Bayswater Road, between the Marble Arch and Notting Hill Gate, in Westminster, and in Kennington Road. In 1863, a line 1¾ miles in length was laid by Mr. Train, and opened, in the Potteries district, for the Staffordshire Potteries Street Railway Company, between Burslem and Hanley. After a brief experience of the inconveniences of the step-rail, Mr. Train's lines laid in London were removed, whilst the Birkenhead tramway and the Potteries tramway were only saved from extinction by the timely substitution of flat grooved rails for the step-rails. The grooves in the new rails were sufficiently roomy to afford free play for the flanges of the wheels, at the same time that they were sufficiently narrow to prevent the wheels of common-road vehicles from entering them.

On streets and roads being in comparatively good condition, with cabs and omnibuses in common use, great numbers of which were available for general circulation at reasonable fares, the need for tramway accommodation was less urgent in England than elsewhere. The advocates of tramways, discouraged by the sensational failures of the first tramways, retired for a time. Mr. Beresford Hope said, 'I have often been button-holed in society about it, and I should say that the general population of

London look upon the extension of tramways with dislike, and with apprehension.'

In fine, the career of the step-rail tramway was ended. However it may have been tolerated in America, it was hated in England; and only after an interval of some years—in 1865 and 1866—was the movement for the construction of tramways revived.

It must be noted, however, that, obviating the vice of the step-rail, flat rails were laid in Salford, on Mr. John Haworth's system, about the year 1862, consisting of two parallel lines of smooth iron plates, 6 inches wide and ½ inch thick, and a central grooved rail, similar in section to an inverted bridge-rail. These rails were laid upon and screwed down to longitudinal timber sleepers, and finished flush with the surface of the pavement. Whilst the wheels of the vehicle rolled freely over the tram-plates, a small guide-wheel, having a central flange, ran upon the central rail. The guide-wheel was hung from the front of the ordinary omnibus, and was raised or depressed at will by the driver. This triple-rail system, known as the 'on-and-off' system, was in operation for upwards of eight years; but it was too weak, insomuch that it worked loose at the joints, and the ends occasionally opened up, making dangerous footing for the horses. Besides, it was open to the objection of slipperiness, and the episodical tramway was eventually removed.

# CHAPTER II.

## MODERN TRAMWAYS IN THE UNITED KINGDOM—THE FIRST LIVERPOOL TRAMWAY.

In November 1865, a show piece of tramway was laid in Castle Street, Liverpool, with the 'crescent rail,' as in fig. 17, designed by Mr. J. Noble, on which great expectations were based. The crescent rail, which was certainly flat enough and unassuming enough, had been employed in the construction of tramways in the United States, and, as it lay perfectly level with the pavement of the street, it was hailed by its admirers as a satisfactory solution of the problem of a non-obstructive street railway.

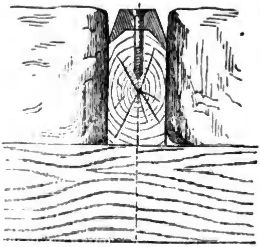


FIG. 17. Crescent rail, by Mr. J. Noble. Scale $\frac{1}{8}$.

The rails were laid on and screwed down to longitudinal bearers, which rested on cross sleepers. A small groove, or slit opening, was left in the pavement, to clear the flanges of the wheels. The provision thus made for clearing wheel-flanges was insufficient, and it was necessary in practice to employ special appliances for sweeping the groove clear of obstructive matter, whilst the tractive resistance must have frequently been excessive. Besides, the unprotected edges of the paving were liable to breakage. Mr. Noble's system was finally abandoned, though it formed part of the original scheme of the Liverpool tramways; and the sample line did good service in allaying the apprehensions of the timid, and in silencing the objections of the fastidious. The sample piece was removed after it had lain four years in Castle Street. The type of rail finally adopted for Liverpool, was formed with a flat level surface, having a narrow groove to receive and guide the wheel-flanges.

In 1866 and 1867, application was made to Parliament for power to construct a system of tramways in Liverpool, for which an Act was obtained in 1868. This was the first English system of tramways for passenger traffic that was authorised by Act of Parliament. The works were constructed by Messrs. Fisher & Parrish, of Philadelphia, under Mr. George Hopkins as engineer-in-chief, and were commenced in May 1869. The South Line, from the Exchange to Dingle, 3 miles 560 yards in length, was opened on November 1, 1869. The North Line, from Old Haymarket to Spillow Lane and Whitechapel Street, 2 miles 700 yards long, was opened on September 1, 1870; and the line on Aigburth Road, which has since been removed, 1 mile 260 yards long, was opened a year later, on September 1, 1871. Thus the total authorised length of tramway, or of streets traversed by tramways, amounted to 6 miles 1520 yards, and it was constructed in the space of about two years and three months. The existing system is about 5¾ miles in length, thus:—

| | Miles. | Yards. |
|---|---|---|
| Single line . . . . . . | 2 | 820 |
| Double line . . . . . . | 3 | 630 |
| Total . . . . | 5 | 1,450 |

The system is like a catharine wheel: it consists of an inner circle, a mile and a quarter long, from which two lines fly off. The inner circle is always worked in one direction, and then the carriages shoot off to the north.

The gauge of the Liverpool tramways was determined to be 4 feet 8½ inches—the same as the national railway gauge. But it was not fixed at that width with any view to a possible communication with railways. As a matter of fact, railway waggons cannot run over the ordinary groove-rails of tramways laid to the railway gauge. The gauge of 4 feet 8½ inches was introduced in the Act, because, when the promoters first applied to Parliament, they were obliged to apply as for a 'railway,' since the word 'tramway' was not to be found in the standing orders, and they were under the necessity of accepting the only gauge allowed for railways.

The form of the rails adopted in the original construction of the Liverpool tramways, was of a flat grooved section, such as had been found to answer satisfactorily at Birkenhead, though narrower: weighing 40 pounds per yard, about 1 inch in thickness, and having a sectional area of about 4 square inches. Rails of similar but larger section were afterwards employed, weighing 45 pounds per yard, shown in fig. 18. The rail was little else than a flat bar, having a narrow and shallow groove in its upper surface, with a fillet on the lower side, and bedded on a longitudinal sleeper. The rail was 4 inches wide and 1⅜ inches in thickness. The groove was formed with sloping sides, and was ¾ inch in depth, with a width of ⅝ inch at the bottom, and double this width at the surface of the rail. The tread, or rolling surface, for the wheels, had a width of about 2 inches, when, of course, the inner edge of the tread was at the half-width of the rail; whilst the ledge on the other side of the groove was about ⅞ inch wide at the surface, and was corrugated transversely, to prevent slipperiness for horses. The rails were bedded on timber sleepers, 4 inches wide and 6 inches in depth, and were fished with ⅞-inch wrought-iron plates, 12 inches long and 4 inches wide, applied below the joint, let flush into the upper side of the sleeper, as shown in fig. 20. The joint was fixed with four vertical spikes,

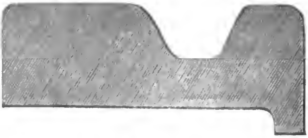


FIG. 18. Early Liverpool rail. Scale ½.

two to each rail, driven through the rails, at the bottom of the groove, and the fish-plate, into the sleeper. The rails were also spiked at intervals to the sleepers. The heads of the spikes were countersunk, and let into the rails to finish flush with the bottom of the groove. The combined sleeper and rail thus presented, for the most part, a vertical surface at each side, against which paving-stones could be closely and evenly laid and jointed. The construction of the way is shown in cross section by fig. 19. To render the way independent for support, on uncertain or on broken ground, the roadway was excavated to a depth of 14¼ inches for the whole width, and a continuous bed of lime-concrete, 7 inches thick, was laid for the whole width of the track, as a foundation, upon which the sleepers were placed. The interspaces between the sleepers were filled up with concrete to the right level for

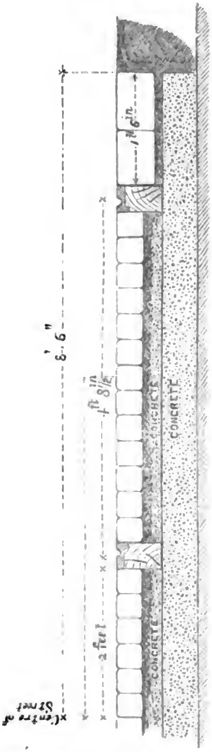


Fig. 19. First Liverpool Tramway. Half-width section. Scale $\frac{1}{24}$.

supporting 4-inch cubes. The sleepers were laid in and spiked to cast-iron clip-chairs, figs. 20, 21, which were placed about 4 feet apart longitudinally, and rested direct on the concrete foundation. The gauge of the rails was fixed by bar-iron cross-ties, $1\frac{1}{2}$ inches deep by $\frac{3}{8}$ inch thick, the ends of which were dovetailed into grooves cast in the inner sides of the chairs. The chairs were 6 inches wide at the joints of the sleepers, and 3 inches intermediately. The road-

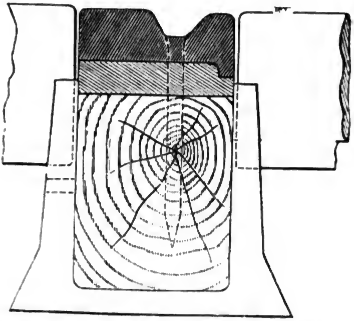


FIG. 20. First Liverpool tramway. Section of rail and sleeper, showing cast-iron chair and fish-joint. Scale $\frac{1}{4}$.

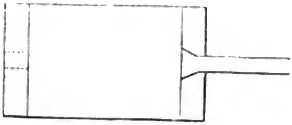


FIG. 21. First Liverpool tramway:—Cast-iron chair for longitudinal sleepers, and cross tie-bar. Scale $\frac{1}{4}$.

way was nearly all of macadam, and the materials for the concrete were taken from the macadam which was lifted to make room for the line, riddled, cleaned, and mixed with blue-lias lime; whilst the whole of the surface between the rails, and for a width of 18 inches beyond the outer sides of the rails, was paved with Welsh granite sets—4-inch cubes between the rails, and sets of 6 inches in depth for the outer 18-inch spaces. The outer width, 18 inches, was provided in the Act, and it defined the marginal boundaries of the breadth of roadway to be maintained by the tramway company. That width was, and is now, accepted as a fair compromise; and, says Mr. J. Morris, 'it does fairly represent the extent of possible injury even which the tramway can do to the road, and it is accepted universally on the Continent, and almost universally in America, and is the recognised standard.'[1]

The 18-inch width of margin is both necessary and sufficient for maintaining the stability of the line, when it is laid in a non-paved or macadamised street, and for affording a foothold for the tram-horses when they traverse the rails. 'I remember,' says Mr. Hopkins, 'that our first Bills were introduced with 9 inches only outside the rails, but the width was increased to 18 inches in Committee.'[2]

Where the lines of tramway were double, in Liverpool, they were laid at a clear distance, apart, of 4 feet between the rails, giving a 'four-foot,' corresponding to the 'six-foot' of railways.

The gradients of the Liverpool lines of tramway are various. Liverpool is a very hilly town. The maximum gradient is 1 in 19.

---

[1] *Report of the Select Committee on Tramways Bill,* 1870.

[2] *Ibid.*

The practice initiated at Liverpool has ruled the general dispositions of tramways in other parts of the country.

In 1869, the North Metropolitan Tramways Company were authorised to lay tramways on the Whitechapel, Mile End, and Bow Road; and, in 1870, they were empowered to lay extensions to Aldgate, at the west end, and to Stratford, Leytonstone, and Bromley, at the east end. In 1871, they obtained additional powers to lay tramways in the north and east of London, which made a total of 30½ miles of tramway authorised to that company.

In 1869, also, Acts were passed for the construction of the Kennington, Brixton, and Clapham routes, from Westminster Road, by the Metropolitan Street Tramway Company; and the routes from Pimlico, by Vauxhall, to Greenwich, by the Pimlico, Peckham, and Greenwich Tramway Company. These two companies were, by their Acts, empowered to construct and work tramways in nearly all the main metropolitan thoroughfares on the south side of the Thames, comprising twenty-five miles of streets. They were amalgamated, in the end of 1870, as the London Tramways Company.

In 1870, the London Street Tramways Company were authorised to lay tramways on the north side of London, from Lower Holloway to the south end of Hampstead Road, and from Kentish Town to King's Cross.

In the beginning of 1873, forty-two miles of tramway had been opened in the streets of the Metropolis; the length was increased to sixty-one miles in 1876. Under the stimulus afforded by the rapid spread and successful operation of the several systems at work, Acts were applied for and obtained, authorising the laying of tramways in many cities and towns in the provinces:—

In 1868 an Act was passed for 1 tramway.
1869 Acts were passed for 3 tramways.
1870 „ „ „ 7 „
1871 „ „ „ 7 „
1872 „ „ „ 16 „
1873 „ „ „ 10 „
1874 „ „ „ 6 „
1875 „ „ „ 7 „

These, and other tramways of earlier date, are recited in the annexed table. The lengths of line, single and double, authorised and opened to the public,[1] are added.

The total lengths of streets traversed by tramways, in the United Kingdom, at June 30, 1876, were as follows:—

| | Miles. |
|---|---|
| England and Wales . . . . . | 132·22 |
| Scotland . . . . . . . | 41·30 |
| Ireland . . . . . . . | 25·09 |
| Total . . . | 198·61 |

---

[1] Partly abstracted from the *Tramways Return*, 1877.

TRAMWAYS AUTHORISED AND OPENED IN THE UNITED KINGDOM, AT JUNE 30, 1876.

| Years in which Acts were passed | Name of tramway | Length of roadway on which tramway is authorised | | | Length of road on which tramway has been opened to the public | | | Capital expended |
|---|---|---|---|---|---|---|---|---|
| | | double | single | total | double | single | total | |
| | | m. ch. | m. ch. | m. ch. | m. ch. | m. ch. | m. ch. | £ |
| 1860 (by permission) | Birkenhead . . . . | — | — | — | — | — | — | |
| 1863 (private) | Staffordshire Potteries . . | — | 1 60 | 1 60 | — | 1 60 | 1 60 | |
| 1868 | Liverpool . . . . . | 3 29 | 3 40 | 6 69 | 3 29 | 2 37 | 5 66 | |
| 1869, 1870, 1871 | North Metropolitan . . | 30 0 | 0 40 | 30 40 | 30 0 | 0 40 | 30 40 | 684,632 |
| 1869, 1870 | London . . . . . | 20 20 | 5 0 | 25 20 | 20 20 | 5 0 | 25 20 | 414,723 |
| 1870 | London Street . . . . | 5 40 | — | 5 40 | 5 40 | — | 5 40 | 153,566<br>Dec. 1876 |
| 1870, 1872, 1875 | Glasgow Street (owned by Corporation) . . . . | 22 73 | 1 12 | 24 5 | 15 12 | — | 15 12 | 210,500 |
| 1870 | Glyn Valley . . . . | — | 10 54 | 10 54 | — | 7 51 | 7 51 | 16,465 |
| 1870, 1874 | Plymouth, Stonehouse, and Devonport . . . . | — | 1 83 | 1 83 | — | 1 83 | 1 83 | 35,983 |
| 1870 | Portsmouth Street . . | — | 2 19 | 2 19 | — | 2 19 | 2 19 | 12,500 |
| 1871 | Cardiff . . . . . | — | 3 69 | 3 69 | — | 2 63 | 2 63 | 35,000 |
| 1871, 1873 | Dublin . . . . . | 21 50 | 1 65 | 23 35 | 15 0 | 1 37 | 16 37 | 235,827 |
| 1871 | Edinburgh Street. . . | 10 4 | 3 26 | 13 30 | 10 4 | 3 26 | 13 30 | 218,595 |
| 1871 | Greenock Street . . . | 8 79 | 0 78 | 9 77 | 2 11 | 0 34 | 2 45 | 31,412 |
| 1871 | Lowestoft and Yarmouth . | — | 2 0 | 2 0 | — | 2 0 | 2 0 | 30,000 |
| 1871 | Vale of Clyde . . . | 4 3 | 0 8 | 4 11 | 3 61 | 0 30 | 4 11 | 118,114 |
| 1872 | Aberdeen District . . | — | 11 15 | 11 15 | — | 2 52 | 2 52 | 18,240 |
| 1872, 1873, 1875 | Belfast Street . . . | 3 40 | 5 0 | 8 40 | 3 40 | 5 0 | 8 40 | 84,500 |

as taken
r a single
cluding a
ost rails ;
the depth
n ground,
9 inches
rrespond-
ngitudinal
d. These
vith Port-
l with river
excavated
r the rails.
p, were laid
, with bar-
the gauge
ked to the
ooves, with
levelled up
The whole
etween and
y to form a
these were
nd rammed.
of very little
ere wanting
s had been
hairs would
r inwards or
not sufficient
afforded by
d. Besides,

# CHAPTER III.

## TRAMWAYS IN THE METROPOLIS—THE LEEDS TRAMWAYS.

SYSTEMS of tramway, like those of Liverpool, were adopted in the construction of the earlier portions of the tramways which were laid in London, under Mr. George Hopkins, as engineer:—the greater part of the North Metropolitan Tramways, of which the first section, from Whitechapel to Bow, was opened in May, 1870; and the original Metropolitan Street Tramway (now a part of the system of the London Tramways Company), $5\frac{1}{4}$ miles long, from Westminster Bridge to Brixton Church, Stockwell, Clapham Common, and Brixton Hill—also opened in 1870. The rails were of the form and section of the Liverpool rail, 4 inches wide, and $1\frac{3}{8}$ inches thick, weighing 45 pounds per yard. The system of construction, shown in fig. 22, was similar to that at Liverpool. The stone

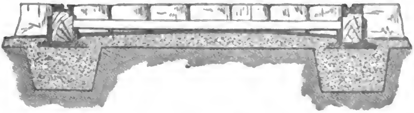


FIG. 22. North Metropolitan Tramway and London Tramways. First lines. Scale $\frac{1}{30}$.

pavement, or the macadam of the street, was taken out for a width sufficient for a double line, or a single line of tramway, as the case might be, including a clear space, 2 feet wide, beyond the outermost rails; and for a depth of about 9 inches, which was the depth of ordinary sets in the Metropolis. In the open ground, thus exposed, longitudinal trenches, about 9 inches deep and 16 inches wide, were excavated, corresponding to the position of the rails and the longitudinal sleepers by which they were to be supported. These trenches were filled with concrete made with Portland cement, or with hydraulic lime, mixed with river ballast, and made up to the level of the excavated ground, to form longitudinal foundations for the rails. The sleepers, 4 inches wide and 6 inches deep, were laid in cast-iron clip-chairs, by means of which, with bar-iron cross-ties, dovetailed at the ends, the gauge was maintained. The rails were spiked to the sleepers by vertical spikes through the grooves, with countersunk heads, and the structure was levelled up by concrete, packed under the sleepers. The whole area was then filled up with concrete, between and outside the sleepers, to the level necessary to form a foundation for the paving stones, and these were bedded on a layer of sand, and grouted and rammed.

The dovetailed tie-bars proved to be of very little use; they were liable to rust away, and were wanting in precision, for unless the dovetailings had been tightly and exactly fitted, so that the chairs would have been prevented from shifting, either inwards or outwards, the transverse connection was not sufficient to maintain the rails, when the support afforded by the pavement was removed or impaired. Besides, tie-bars placed between the paving sets are in the way, and interfere with the convenience for paving. Again, tie-bars laid in dovetails in brackets, like those just described, work gradually to the surface, and even above the level of the paving. In such a contingency they are removed, which is the best thing to be done.

Moreover, the flat rail and the vertical spike or bolt-fastening made a defective combination. It is scarcely necessary to say that, at best, the form of the flat rail combined the maximum of material with the minimum of strength and stiffness, whilst the vertical spike-fastening, though it is simple, and appears at first sight to have been happily devised, is deficient in strength and in durability, and contributes nearly nothing towards the union of the rail with the sleeper. The rail, especially at the joints, is liable to spring, and the spikes with their shallow countersunk heads and limited bearing surface, are liable to yield and to wear; the spikes in consequence are gradually loosened, and the heads are lifted, and torn or broken off. The spike-heads are further exposed to damage from the wheel-flanges, which, like the rail, became worn, ground in the groove, and occasionally split the rail.

Wherever there is vertical movement, of course, an entry for water is made, pumping action ensues, and rain-water alternately sinks through the spike-holes and by the sides of the rails, and rises to the surface laden with sand and other detritus. The rails and sleepers are gradually undermined, the sleepers are deformed by blows, and the vertical instability is by so much increased.

With a view to ameliorate the difficulties of the vertical fastening, as well as to provide an iron tie of a substantial character in place of the delicate dovetails, Mr. Joseph Kincaid, as engineer, employed transverse sleepers in the construction of the Pimlico, Peckham, and Greenwich section of the London Tramways, opened in August, 1871. Transverse sleepers, fig. 23, were placed in the bottom of the excavation, to afford an increase of bearing surface on the ground, and to receive the longitudinal sleepers which were placed upon them. The transverse sleepers, which were placed at intervals of 5 or 6 feet, also afforded a substantial means of tying the longitudinal sleepers to the gauge. Instead of attachments in tension, like those of the dovetail bars, cast-iron brackets, two to each cross sleeper, were employed as abutments, one bracket outside each longitudinal sleeper, to which the brackets were spiked. The brackets were spiked to the longitudinal sleepers near to their lower surfaces, whilst they were extended up the sides of the sleepers to afford a direct, or at least nearly direct, resistance to centrifugal stress. By this combination, the indirectness of the sleeper, as opposed to lateral stress above, was liberally compensated by the general stiffness of the structure.

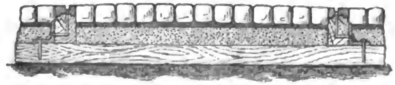


FIG. 23. Pimlico, Peckham, and Greenwich section of London Tramways. Scale $\frac{1}{30}$.

An additional fillet was applied to the under surface of the rail, fig. 24, at the outside, so that now the rail was formed with two fillets, one at each side, that it might be more firmly bedded on the sleeper than the rail having only one fillet. It was found necessary not only to provide, by the inside fillet, the means of resistance to the lateral stress of the cars through the flanges of their wheels; but, likewise, means of opposing the lateral action of cross strokes from the wheels of common road vehicles, which traversed the road in all directions. Hence the addition of the second fillet, at the outer side of the rails. The longitudinal sleepers were carefully rebated to receive the rails, which were fixed to them, as before, with vertical spikes through the groove. The adoption of the double fillet, though, in fact, a reversion to old-established American practice, constituted an intelligent advance in English practice with the grooved rail.

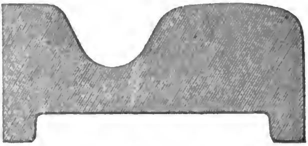


FIG. 24. London Tramways. Section of rail. Scale ½.

The wearing surface of the rail was slightly rounded transversely, having about $\frac{1}{16}$ inch rise, by which the thickness was increased to $1\frac{7}{16}$ inches, though the motive for rounding is not obvious. The groove was made wider than before, being $1\frac{3}{8}$ inches at the surface; and it was rounded at the bottom to a circular form, thus at the same time strengthening the rail by the substitution of a round for a flat contour for the grooves, and facilitating the dislodging of detritus. The splay of the outer side of the groove was, at the same time, slightly greater than in the previous rail. The new rail was 4 inches wide, had a sectional area of 4¾ square inches, and weighed 48 pounds per yard.

For laying in the foundation, the surface of the roadways was removed, and the ground was excavated to a depth of from 12 inches to 14 inches, to receive the cross sleepers. After the longitudinal sleepers were laid and fixed, with the rails complete, they were brought up to the required level by concrete packing below the cross sleepers; then the whole space was filled with lime concrete to the height necessary for receiving the pavement of stone, or of asphalte, whichever was to be laid, for, in some parts of the way, asphalte was used instead of granite for paving. For asphalte, the concrete was required to be brought up higher than for stone, since it was only 1½ to 2 inches deep, whilst stone was 6 or 7 inches deep; and the total cost of construction was greater for asphalte. Much was hoped for from asphalte as a pavement for tramways. Experience has not confirmed such expectations. Asphalte pavement breaks away at the borders next the rail, as well as at the outside; and it must be admitted that as a foothold for horses, in starting the cars, it has been a dead failure.

Mr. Kincaid, having, in the Peckham Tramway, proved the advantage of the cross sleeper, as a useful element in a timber structure, employed it in the construction of the first section of the Leeds Tramways—

the line to Headingley—which was opened in October 1872. The gauge was 4 feet 8½ inches. The ground was excavated to a depth of 7¼ inches—the depth of the rail plus that of the longitudinal sleepers—for the whole width of the way; and trenches about 9 inches wide, were cut in the excavated bottom, and filled with concrete, flush with the bottom, to carry the sleepers. The cross sleepers, 6 inches wide and 4 inches deep, were laid in the concrete of the transverse trenches, about 3 feet apart, flush with the surface; and thus a continuous level foundation was formed for the longitudinal sleepers and the rails. The longitudinals, 4 inches wide and 6 inches deep, were fixed to the transverse sleepers by cast-iron brackets, one on each side of each longitudinal sleeper, spiked to both timbers. The rails, weighing 47½ pounds per yard, were flat-grooved, 4 inches wide and 1¼ inches thick, with two ½-inch square fillets on the underside, let into the sleepers; they were spiked through the groove to the sleeper. A bedding of furnace ash or clinkers, 2¼ inches thick, was laid over the bottom, on which paving sets, 5 inches deep, were laid.

On this system, an economy of excavation, as well as an economy of concrete, was effected, by employing concrete for the support of the sleepers exclusively. By the interposition of a bed of ashes laid uniformly over the whole surface, it was designed that the paving should rest equally over the sleepers and the direct excavated surface.

# CHAPTER IV.

## THE GLASGOW CORPORATION TRAMWAYS.

An Act of Parliament was passed in 1870, for the construction of 'The Glasgow Street Tramways,' by a private company. The powers conferred by the Act were, in the same year, transferred to the Corporation of Glasgow, by whom, accordingly, the tramways of Glasgow have been constructed.

In designing the first tramway, the engineers, Messrs. Johnstones & Rankine, developed the application of the transverse sleeper for giving bearing surface and for strength. They adopted a modified form of the old flat-grooved rail, in combination with longitudinal and transverse sleepers, and bituminous concrete, and produced a structure which surpassed all others that had previously been laid for tramways, in strength and solidity. The system of construction is illustrated by fig. 25. It was adopted for the first contract, which was entered into in September 1871. The first portion of the line made under the contract was 2 miles 300 yards, and was opened in August 1872. By the end of the year 1872, 9 miles of tramway were completed and opened, and the whole of the tramways executed under the first contract, passing over 9⅔ miles of streets, were completed in June 1873.

In designing the rail, a single broad fillet, on the lower side, under the groove, was substituted for the pair of lateral fillets employed in other rails made at that time. The fillet was let into the longitudinal sleepers, and, besides providing the needful lateral resistance at either side, it aided in strengthening the rail at the weakest part of the section—under the groove—whilst it afforded a deeper bearing for the countersunk heads of the vertical bolts employed for fixing the rail to the sleeper. The longitudinal sleepers rest in cast-iron chairs formed with broad soles, spiked to transverse wood sleepers laid in concrete. The bolt, having a slotted head, was screwed into a nut with a washer at the underside of the longitudinal sleeper, and a hasp was applied to pre-

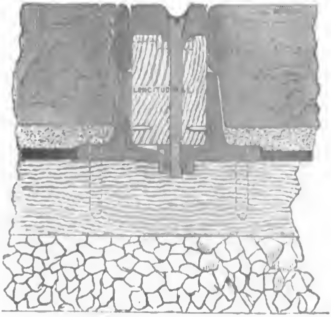


Fig. 25. Glasgow Corporation Tramways:—First system. Scale ⅛.

vent the nut from turning when the bolt was required to be tightened up. But the hasp was abandoned after the construction of the first section.

The works under this contract were as follows, being double way, except 1,110 yards, or about two-thirds of a mile, which were single way:—

| | Miles. | Yards. |
|---|---|---|
| No. 1 Tramway.—Whiteinch, *viâ* Partick and Trongate, to Bridgeton . | 5 | 128 |
| No. 2 Tramway.—Great Western Road, *viâ* Sauchiehall Street, Renfield Street, Jamaica Street, to Port Eglinton . . . . . . | 3 | 967 |
| No. 3 Tramway.—Junction of the 1st and 2nd Tramways, *viâ* Derby Street | 1 | 78 |
| (9⅔ miles) | 9 | 1,173 |

The gauge of the rails, according to the Act of 1870, was required to be equal to the railway gauge, 4 feet 8½ inches. But a new element was introduced by the Act passed in 1871 for the Vale of Clyde Tramways, according to which their lines were to be constructed for the transit of railway rolling stock; and it was further provided that the Corporation should, if they thought fit, construct the Glasgow tramways to the same gauge as that of the Vale of Clyde lines, to secure a uniformity of gauge throughout the Glasgow district. It behoved the authorities, therefore, to look in advance; and while the contract for the first portion of the tramways was being drawn up, in 1871, it occurred to the engineers that, in order to give passage to railway waggons, the Vale of Clyde lines, and therefore also those of the Corporation, if the gauges were to be uniform, must be less than the normal standard gauge; for—what is strange at first sight—the gauge of 4 feet 8½ inches in a grooved rail does not answer for railway waggons. The reason becomes apparent when it is considered that the groove is not wide enough to clear the backs of the tyres. These are never less than 4 feet 5½ inches apart, a width which is 3 inches less than the normal gauge, equivalent to 1½ inches at each rail. But, as the width of the groove in the tram-rail is commonly limited to 1⅛ inches, or, at the most, to 1¼ inches, the flanges of waggons, obviously, could not enter at all.

A correspondence was, therefore, instituted by Messrs. Johnstones & Rankine, in September 1871, with a view to the establishment of a uniform gauge at the outset, as a standard for all the tramways in process of construction, or to be constructed, in or near Glasgow: such that, whilst the gauge should be continuous throughout the whole of the group, it should be adapted for the transit of railway vehicles. Messrs. Johnstones & Rankine proposed to contract the gauge from the ordinary width, by three quarters of an inch, to 4 feet 7¾ inches, maintaining the minimum width of groove, already adopted by them, 1¼ inches. By this compromise, they would shift inwards the inner sides of the grooves of the two rails for each line, to the distance apart of 4 feet 7¾ inches minus twice 1¼ inches, or to 4 feet 5¼ inches. In this way, the line would be adapted to receive railway waggons, with a total lateral clearance of ¼ inch between the backs of the tyres and the inner edges of the grooves. It was apparent, nevertheless, that the 1¼-inch groove would be just wide enough to receive the flanges of railway waggons, which were of the same width, or thickness,—1¼ inches. But the wedging which would have, in consequence, to take place, if the wheels were to run on their treads or rolling surfaces, was obviated by the shallowness of the groove of the Glasgow rail—the depth being only ¾ inch; for it followed that the wheels would run on their flanges, which being more than ¾ inch deep, would touch the bottom of the groove, and so prevent the wheel settling down and wedging itself into the rail.

Mr. Hopkins, as engineer for the Vale of Clyde tramways, assented to the proposition for securing uniformity of gauge, and in the first instance, recommended a gauge of 4 feet 7⅛ inches. For the purpose of settling the choice of these two widths, Messrs. Johnstones & Rankine made arrangements for and conducted experimental trials with a short line of tramway laid to a gauge of 4 feet 7¾ inches, with the rails of the Glasgow tramways, and at the charge of the Corporation, within the station of the Glasgow and South Western Railway. Mr. Hopkins and others were present at the trials, which took place on October 24, 1871. Railway waggons were run over the piece of tramway, in a manner which was quite satisfactory; and the results of the trials led to the adoption, by general consent, of the gauge of 4 feet 7¾ inches, for all the tramways of the Glasgow district.

The total width of the tramway, for a double line, amounted to 16 feet 11¼ inches, constituted as follows:—

| | Feet | Inches |
|---|---|---|
| Width of gauge, 4 feet 7¾ inches × 2 = . | 9 | 3½ |
| Width of interspace between lines of way . | 3 | 11½ |
| Four widths of rolling surface of rails, 1⅞ inches × 4 = . . . . . . | 0 | 7½ |
| Two outer margins of pavement, 18 inches × 2 = . . . . . . | 3 | 0 |
| Total width . . . . | 16 | 10½ |

For a single line, the total width is 7 feet 11½ inches.

The excavation for the tramways was made to a uniform depth of 16¼ inches below the surface of the street, for the whole width. A bed of bituminous concrete, 4 inches thick, was laid over the whole of the excavated bottom. The concrete consisted of slag fresh from the furnaces, thoroughly dry, broken to a 2-inch ring gauge, and British bitumen made from pure coal-tar pitch. The bitumen was to be used at the boiling point, and mixed in the proportion of 31 pounds per cubic foot of slag. The transverse sleepers were laid on the concrete bed, and after the longitudinal sleepers and rails had been correctly laid and adjusted, the spaces between the cross sleepers were made up with concrete of the same composition, flush with the upper surface of these sleepers. A ½-inch stratum of bitumen was floated over this new level. Concrete was also packed under the longitudinal beams in the intervals between the chairs.

The rails, fig. 25, weighed 60 pounds per yard; they were 4 inches wide, and 1⅝ inches thick at the tread. The rolling surface was 1⅞ inches wide; the groove was 1¼ inches wide and ¾ inch deep, formed semicircularly at the bottom; and the inner flange was ⅞ inch thick, and corrugated at the upper surface. The rolling surface was slightly rounded transversely; the fillet on the underside was ⅜ inch deep, and so increased the total depth of the rail to 2 inches; the rails were rolled to 24 feet in length, except 5 per cent. of the total quantity, which is of shorter lengths, not less than 14 feet. The bolt-holes in the grooves were ⅝ inch in diameter, countersunk to a diameter of 1 inch. The rails were to be made from piles of selected puddle-bars of mine iron, to produce a hard granular rolling surface, and to be of tough fibrous iron at the underside. They were bolted to the sleepers with ⅝-inch bolts, of which there were eight to each rail of 24 feet long.

A portion of the points and crossings were to be of cast iron, 2 inches thick, and others of wrought iron, 1½ inch thick, corrugated at the surface; the chairs are of cast iron.

Three-eighths inch fish-plates, 12 inches long, were placed under the ends of the rails.

The longitudinal sleepers are of American white oak, 4 inches wide and 6 inches deep, secured to the chairs by ⅝-inch oak pins; the transverse sleepers are of Baltic timber, 4 inches deep, 7 inches wide at the joints of the longitudinal sleepers, and 6 inches wide intermediately. All the timber was creosoted with 8 pounds of creosote per cubic foot of timber.

The interspaces, together with a breadth of 18 inches on each side of the way, were to be paved with granite from Furness Quarry or Bonawe Quarry. The stones were to range from 4 inches to 7 inches deep, as might be required, and to be laid on a bed of sand of from 1 inch to 1½ inches deep, laid on the bituminous coating. The stones were to be jointed.

for 3 inches on each side of each rail, with British bitumen; the remainder with lime-grout. The surface of the pavement was formed with a lateral slope of $\frac{1}{8}$ inch in one foot, from the centre line.

The use of bitumen for the joints was abandoned, as on experiment it was found that the bitumen ran and spread beyond the specified width, and under some of the stones; and the design could not profitably be carried out.

The contractor was to maintain the whole of the work for six months after completion, and to replace all rails failing within twelve months. He could re-use, after re-dressing, the paving-stones interfered with, so far as they were suitable for the work.

The total cost of construction of the tramways under the first contract was as follows:—

GLASGOW CORPORATION TRAMWAYS.

*Cost.*

| 1872–73 | Length, single line | Total cost | Cost per lineal yard | Cost per mile, single line | Charge for maintenance for six months |
|---|---|---|---|---|---|
| | yards | £ | £ | £ | £ |
| No. 1, 1st piece | 8,281 | 27,850 | 3·363 | 5,919 | 30 |
| „ 2nd „ | 6,286 | 16,144 | 2·568 | 4,519 | 100 |
| „ 3rd „ | 2,920 | 6,258 | 2·143 | 3,772 | 20 |
| No. 1 . . . | 17,487 | 50,252 | 2·873 | 5,058 | 150 |
| „ 2 . . . | 12,234 | 30,835 | 2·521 | 4,437 | 20 |
| „ 3 . . . | 3,195 | 7,442 | 2·329 | 4,100 | 10 |
| Totals . . | 32,916 | 88,529 | 2·689 | 4,733 | 180 |

The variations in the cost per yard and per mile for the different pieces, arise chiefly from the item of paving. In the first piece, of No. 1 tramway, the roadway was of macadam, and the tramway was laid with entirely new paving; whilst in the third piece the roadway was paved throughout, and the old stones were re-dressed and utilised for the tramway. In the other pieces, the roadway was partly of macadam and partly of paving. The items of costs for paving, included in the above total costs, were respectively as follows:—

GLASGOW CORPORATION TRAMWAYS.

*Cost of Paving.*

| 1872–73 | Cost of paving | Cost per lineal yard, single line | Cost per mile, single line |
|---|---|---|---|
| | £ | £ | £ |
| No. 1, 1st piece . . | 12,370 | 1·494 | 2,629 |
| „ 2nd „ . . | 4,195 | 0·667 | 1,175 |
| „ 3rd „ . . | 1,010 | 0·346 | 609 |
| No. 1 . . . . . . | 17,575 | 1·005 | 1,769 |
| „ 2 . . . . . . | 8,476 | 0·693 | 1,220 |
| „ 3 . . . . . . | 1,697 | 0·531 | 935 |
| Totals for paving . | 27,748 | 0·843 | 1,484 |
| Totals for tramways proper . . | 60,781 | 1·846 | 3,249 |
| Total whole cost . | 88,529 | 2·689 | 4,733 |

From these data it appears that the average cost of construction per mile of double ways was—

For the tramway proper £6,498 per mile, or 69 per cent.
For paving . . . 2,968 „ 31 „

Total . . £9,466 „ 100 „

### SCHEDULE OF PRICES FOR FIRST CONTRACT, 1872–73.

| | s. | d. | |
|---|---|---|---|
| Excavating macadam, and removing the same, for double line | 7 | 0 | per lineal yard. |
| Ditto, for single line | 3 | 6 | „ |
| Lifting causeway, and excavating stuff and removing the same, for double line | 5 | 0 | „ |
| Ditto, for single line | 2 | 6 | „ |
| Furnishing, laying, and completing bituminous concrete, under transverse sleepers, for double line | 14 | 2 | „ |
| Ditto, for single line | 6 | 8 | „ |
| Furnishing, laying, and completing bituminous concrete, upon the preceding layer, to 1½ inch below paving stones 6 inches deep, or to from 1 to 1½ inch below paving stones 7 inches deep, for double line | 14 | 2 | |
| Ditto, for single line | 6 | 8 | „ |

| | £ | s. | d. | |
|---|---|---|---|---|
| Rails, laid complete | 9 | 9 | 0 | per ton. |
| Chairs „ | 4 | 10 | 0 | „ |
| Bolts and nuts „ | 16 | 10 | 0 | „ |
| Fish-plates „ | 10 | 5 | 0 | „ |
| Washer „ | 12 | 0 | 0 | „ |
| Spikes „ | 9 | 12 | 0½ | „ |
| Cast-iron points and crossings, laid complete | 7 | 10 | 0 | „ |
| Wrought-iron points and crossings, laid complete | 18 | 0 | 0 | „ |
| Transverse sleepers, creosoted and laid complete:—Joint | 0 | 3 | 0 | each |
| Intermediate | 0 | 2 | 6 | „ |
| Longitudinal sleepers, creosoted and laid complete | 0 | 2 | 4½ | per lineal yd. |
| Ditto laid, not creosoted | 0 | 2 | 2¼ | „ |
| Allowance for extra width of longitudinal beams at points and crossings | 3 | 0 | 0 | per set. |

|  | £ | *s.* | *d.* |  |
|---|---|---|---|---|
| Oak pins, 5½ inches long, ⅝ inch diameter . . . . . . | 1 | 0 | 0 | per 1,000 |
| Filling all bolt, spike, and pin-holes with Archangel tar, per lineal yard of single line . . . | 0·343*d*. per lineal yard. |  |  |  |
| Furnishing and laying sand, 1½ inches deep, under stones:— |  |  |  |  |
| Double line | 0 | 0 | 9 | " |
| Single line | 0 | 0 | 4½ | " |
| Furnishing and laying paving stones, jointing and grouting the same:— |  |  |  |  |
| 4 inches deep, new stones— |  |  |  |  |
| Double line | 2 | 5 | 0 | " |
| Single line | 1 | 2 | 6 | " |
| 6 inches deep, new stones— |  |  |  |  |
| Double line | 2 | 19 | 0 | " |
| Single line | 1 | 9 | 6 | " |

The liberal development of solidity exemplified in the construction of the first contracts for the Glasgow Corporation Tramways, was extended likewise to the subsequent contracts, which are illustrated by Plate II., and will be fully described.

# CHAPTER V.

## LARSEN'S FASTENING—LONDON STREET TRAMWAYS—BELFAST TRAMWAYS.

But a method of fastening the rail to the sleeper was wanted which would be free from the defects of the vertical spike,—a method, the barbarity of which was only rivalled by its simplicity. Mr. Jorgen Daniel Larsen supplied the want, by substituting lateral fastenings for vertical spikes—a system which was patented by him in February 1871, and is represented in fig. 26.

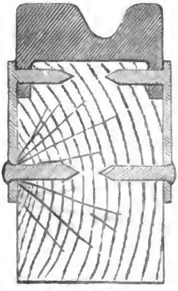


Fig. 26. Side fastening. By Mr. J. D. Larsen. Scale ¼.

'The vertical or upright side of the rail,' he says, 'intended to be fastened to a sleeper, is so made as to extend in the manner of a flange or flanges below the upper surface of the sleeper (longitudinal), either on one or both sides of the sleeper. An aperture is made in each flange, so as to be a short distance below the upper surface of the sleeper, when the rail is placed thereon. To fix the rail to the sleeper, a bent metal piece or half staple is inserted into the hole in the flange and driven home, and is also fixed to the vertical side of the sleeper. The part of the metal piece or half-staple inserted into the hole may be of various forms, and may be so long as to go through the sleeper and to enter also a corresponding hole in the other vertical side of the rail extended as a flange. The metal piece may be of such form as to pass through at once two or more holes in the same flange.'

In the Larsen rail, two important advantages are combined. By the flanges it is virtually increased in depth and in stiffness vertically and laterally; and the fastenings, as applied at the sides, are not only removed from interference of the wheel flanges, but are so placed as greatly to strengthen the attachment of the rail to the sleeper; for, it is apparent that the wide base of attachment afforded by the lateral flanges, creates a leverage of resistance to lateral stress twice as great as the leverage derived from a central vertical spike. There is yet another advantage, that by means of the flanges, the sleeper may be more firmly embraced by the flanged rail than it can possibly be by the shallow filleted rail.

Although, incidentally, the strength of the Larsen rail was increased by the addition of the flanges, it does not appear that vertical strength was, in his earliest designs, made a point in question by the designer; for there is only sufficient depth of flange, 1 inch, to afford room for the fastenings. In point of absolute transverse strength, Larsen's rail had already been anticipated by Livesey's rail, patented in 1839, which will be described in Chapter IX. on iron ways, and which was formed with a flange at each side of considerable depth. Mr. Larsen should, nevertheless, be credited with the merit of introducing the flange-rail into practice in England, as well as the method of the side-fastening.

In the construction of the London Street Tramways, under the charge of Mr. Larsen, the first portion of which was opened in November 1871, he designed and made the first application of lateral fastenings for tram-rails, fig. 27, upon the results of which his patent was based. In this, his first trial, the rails were 4 inches wide, and weighed 60 pounds per yard. They were double-flanged, and were fixed upon longitudinal sleepers, 6 inches deep, by means of side-fastenings, which consisted of three pieces at each side:—a strap 3¼ inches long, ⅝ inch wide, and ⅜ inch thick, and two spikes driven horizontally into the sleeper, through a hole at each end of the strap, the upper spike passing also through a hole made in the flange of the rail. The excavation for the foundation was carried down to a level of 4 inches below the underside of the sleepers, for the whole width of the way. An even bed of concrete, 4 inches thick, was laid upon the bottom, and the longitudinal sleepers were laid directly upon it. The timbers were placed in cast-iron chairs at the points, and the gauge was fixed by means of flat bar-iron ties, at intervals, split and kneed both ways at the ends, and fixed to the sleepers by bolts or spikes, as shown. A 2-inch layer of sand or of gravel was distributed over the concrete

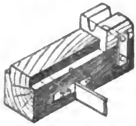


FIG. 27. Larsen's fastening for the London Street Tramways.

surface, to form a bed for the paving, which was laid and grouted in the usual manner. See fig. 28.

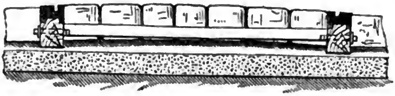


FIG. 28. London Street Tramways. Scale $\frac{1}{30}$.

In this, his first employment of side-fastenings, Mr. Larsen substituted three pieces for the single vertical spike. Not oblivious of the disadvantage of multiplying the number of pieces in a fastening, he reduced them, in his patent, to two in number, as has already been described; and in his next operation, the construction of the Belfast Tramways, he employed the fastening in two pieces, as patented. The works of these tramways were commenced early in 1872, and the first section was opened in the autumn of the same year.

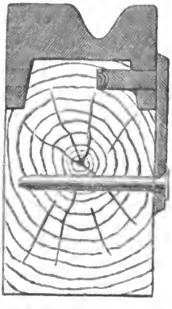


FIG. 29. Belfast Tramways. Section of rail with Larsen's fastening. Scale $\frac{1}{4}$.

The construction of the Belfast Tramways is illustrated by fig. 29. It consists of longitudinal sleepers laid upon cross sleepers enclosed in concrete, the rails being laid on the longitudinal sleepers. The gauge of the way is 5 feet 3 inches, the intermediate space between the two lines of rails of a double line is 4 feet; the breadth of paving at the outer sides of the rails is 2 feet; the tread of the rails is $1\frac{3}{8}$ inches wide, and the total width of the tramway for a double line is constituted as follows:—

BELFAST TRAMWAYS.

| | Feet | Inches |
|---|---|---|
| Two lines, 5 feet 3 inches gauge . . | 10 | 6 |
| Intermediate space . . . . . . | 4 | 0 |
| Two outside breadths of 2 feet each . | 4 | 0 |
| Four widths of tread, 1⅞ inches . . | 0 | 7½ |
| | 19 | 1½ |

The ground was excavated to a uniform depth of 11½ inches below the permanent surface, for the whole width of the tramway, double or single. Cross sleepers of wood, 4 inches deep, by 6 inches wide, and 7 feet in length, were laid on the bottom of the excavation at intervals of 5 feet between centres, and upon these the longitudinal sleepers, 3⅞ inches wide, by 6 inches deep, were laid and fixed by cast-iron brackets, weighing 5 pounds each. There was but one bracket at each intersection, placed alternately at the inside and the outside of the longitudinal sleeper; fixed by four spikes to each bracket.

The rails weigh about 62 pounds per yard, they are 3⅞ inches wide and 1½ inches thick; the side flanges are 1¼ inches deep, and $\frac{7}{16}$ inch thick at the edge, making the total depth of the rail 2¾ inches. The tread is 1⅞ inches wide, the groove is 1⅛ inches wide and $\frac{15}{16}$ inch deep, and the outer ledge is ⅜ inch thick at the edge. The side-fastening of the rail to the sleeper is of two pieces:—an iron plate or strap, ¼ inch thick, having a spike welded to it at the upper end, which passes through the flange of the rail, and a hole near the lower end, through which a large spike is driven nearly through the sleeper. The fastenings were applied alternately to each side of the rails at short intervals.

After the sleeper and rails were accurately adjusted and packed below the cross sleepers, the spaces between the cross sleepers, and the whole area above them on each side of the longitudinal sleepers, was filled solid with concrete to a total height of about 7 inches above the floor of the excavation, suited for the laying of the paving, which consisted of 4-inch granite cubes, with a ½-inch layer of sand.

# CHAPTER VI.

## DUBLIN TRAMWAYS—VALE OF CLYDE TRAMWAYS.

The superiority of the Larsen rail—as a rail with side-fastenings—to the rails with vertical spike-fastenings, was established by the experience acquired of its capabilities on the London Street Tramways, though in these as well as in the Belfast Tramways subsequently constructed, the system of side-fastening was but imperfectly developed. Mr. Hopkins improved the system of the side-fastener by substituting for the fastener in two or in three pieces, a solid staple or 'dog,' in one piece, which he employed in the construction of the Dublin Tramways, of which he was the engineer, and the works for which were commenced in October 1871. The design of the tramway was very simple—four rails laid on four longitudinal sleepers bedded in four longitudinal trenches of concrete: similar to the first system adopted by Mr. Hopkins for tramways in London. The rail, shown in section, fig. 30, weighs 53 pounds per yard; it is 4 inches wide; but though it is thinner than the grooved rails of earlier design, it is deeper, and shows clearly a better distribution of material than in these rails: better even than the

Belfast rail, which was of later construction, and designed by Mr. Larsen. The rolling surface of the Dublin rail is 2 inches wide; the groove is 1⅛ inches wide, and $\frac{11}{16}$ inch deep, with a flat floor; the ledge is ⅞ inch thick at the surface. The rails were fixed upon longitudinal fir sleepers 4 inches wide and 6 inches deep, in lengths of from 18 to 25 feet, rebated to receive the rails. The rails were pressed down and solidly bedded by means of screw-cramps. In this position they were fixed to the sleepers by means of staples in one piece, made of ½-inch round iron, the lower ends of which were barbed. A section of the rail and the sleeper thus fixed together is given in fig. 30. The staples were applied at intervals of 3 feet on each side of every rail, and there was one on each side of the rail at a distance of about 4 inches from each end. At curves in the line, if not severe, the sleepers were in some instances sawn half through the outer side at intervals, and wedges were driven into the cuts until the sleeper took the required curvature. At sharp curves, the sleepers, in short lengths, were sawn to the required curvature. The ends of the rails were stayed with wrought-iron plates, 7 inches long, $\frac{5}{16}$ inch thick, and 2½ inches wide, let into recesses adzed off the sleeper. The intention in applying these plates was to maintain the ends of the rails at the same level.

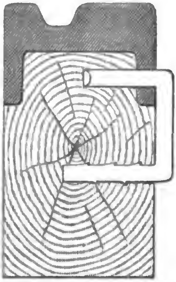


Fig. 30. Dublin Tramways:—Section of rail and sleeper, showing the staple fastening. Scale ¼.

A general section of both lines for a double way is given in fig. 31. The rails of each line are placed to a gauge of 5 feet 3 inches, which is the railway gauge of Ireland, though railway waggons cannot be run on the tramway. There is a clear 4-feet space between the two lines of way, and there are the customary 18-inch breadths of pavement outside the outer rails. The working edge of the groove is at the middle of the width of the rail, or 2 inches from each edge; and the total width of roadway occupied by the double line of tramway is made up as follows:—

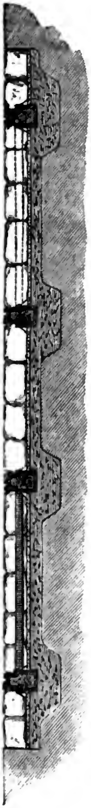


Fig. 31. Dublin Tramways:—Section of the double way. Scale $\frac{1}{48}$.

Dublin Tramways.

| | Feet | Inches |
|---|---|---|
| Two lines, 5 feet 3 inches gauge . | 10 | 6 |
| Intermediate space . . . . . | 4 | 0 |
| Four half-widths of rail . . . | 0 | 8 |
| Two breadths of paving outside . | 3 | 0 |
| Total . . . . . | 18 | 2 |

making a total width of 18 feet 2 inches. Four trenches were cut in the tracks of the rails, to a depth of 18 inches below the level of the roadway, to a width averaging about 2 feet, whilst the intervening surface was excavated to a depth of 11 inches. The excavated space was filled with concrete to a level of about $7\frac{1}{4}$ inches below the surface, forming a level bed for the sleepers. The concrete was made with blue-lias lime, or with Portland cement. The ends of the sleepers were laid in cast-iron chairs, like those of the Liverpool line, page 24, which fitted them tightly, and were fixed to them at the outer side by two nails, one to each end of the sleeper. The inner sides were formed with dovetail and slots, to receive the ends of a tie-bar at each point. Intermediate ties of flat iron were placed at intervals of about 7 feet; they were split at the ends, and formed with right and left knees, in the manner shown in fig. 27, page 50, by which they were nailed or spiked to the sleepers. A bed of sand, 1 inch thick, was laid on the concrete to receive the paving, which consisted of granite sets, 6 inches deep. The transverse joints of the paving, 1 inch wide, were filled with small gravel or shingle, which was rammed into the joints, after which the paving was beaten with ordinary rammers.

The following is a statement of the quantities, with the approximate actual cost, for one mile of double way:—

DUBLIN TRAMWAYS.—QUANTITIES AND APPROXIMATE COST FOR ONE MILE OF DOUBLE WAY, 1871–72.

| | | | s. | d. | £ | s. | d. |
|---|---|---|---|---|---|---|---|
| Excavation . . . | 3,500 cubic yds. | @ | 2 | 0 | 350 | 0 | 0 |
| Concrete . . . . | 1,400 „ | „ | 6 | 0 | 420 | 0 | 0 |
| Sand and shingle . | 400 tons | „ | 3 | 0 | 60 | 0 | 0 |
| Sleepers . . . . | 3,520 cubic feet | „ | 2 | 6 | 440 | 0 | 0 |
| Rails, wrought iron . | 7,040 lineal yards<br>190 tons | „ | £12 | | 2,280 | 0 | 0 |
| Chairs, cast iron . | 8¼ tons | „ | | 8 | 66 | 0 | 0 |
| Nails . . . . | ½ ton | „ | | 24 | 12 | 0 | 0 |
| Cushions . . . . | 0·60 ton | „ | | 10 | 6 | 0 | 0 |
| Staples, 14,080 @ 350 lb. per 1,000 . . | 2⅕ tons | „ | | 26 | 57 | 4 | 0 |
| Tie-bars . . . . | 11 tons | „ | | 16 | 176 | 0 | 0 |
| Laying rails, single line | 3,520 lineal yds. | „ | 1 | 0 | 176 | 0 | 0 |
| Cost of way . . . . . . . | | | | | 4,043 | 4 | 0 |
| Paving . . . . | 9,973 square yards | „ | 5 | 6 | 2,742 | 11 | 6 |
| Carting away débris . . . . . . . | | | | | 50 | 0 | 0 |
| Watching and lighting . . . . . . . | | | | | 120 | 0 | 0 |
| Management and contingencies . . . . . | | | | | 150 | 0 | 0 |
| Total approximate cost per mile of double way . | | | | | 7,105 | 15 | 6 |
| Ditto per mile of single way . . . . . | | | | | 3,552 | 17 | 9 |

The first portion of the lines was opened, between St. Stephen's Green and Rathgar, 2¼ miles, on February 1, 1872. The tramways were fully opened, to a length of 16 miles, early in 1874.

# CHAPTER VII.

## THE VALE OF CLYDE TRAMWAYS.

The Act for the Vale of Clyde Tramways was passed in 1871. They consisted of two sections—from Park House Toll, Glasgow, to Paisley, Johnstone, and Govan; and from Port-Glasgow to Greenock and Gourock. As before remarked, the Vale of Clyde line, between Glasgow and Govan, was, by the Act, to be constructed so as to admit of railway vehicles being passed over it; in fact, to carry loaded coal-waggons from the Govan Railway Station to the ship-building yards on the route. It was laid to the gauge, 4 feet 7¾ inches, which was adopted by general consent for the tramways of the Glasgow district, as already noticed, page 41, and had been applied to the Glasgow Corporation Tramways.

The first piece of the upper section of the Vale of Clyde Tramways—from Park House Toll, Glasgow, to Govan—was constructed by the Corporation of Glasgow, under Mr. Hopkins, as the engineer. The construction was commenced in July 1872, and the line was opened for traffic on the 16th December, 1872. A portion of the lower section—between Greenock and Gourock—1½ miles in length, was opened in July 1873. The remainder of the lower section, 3 miles in length, were constructed by, and leased from, the Corporation of Greenock. The lengths of lines now open are as follows:—

| | | | |
|---|---|---|---|
| Glasgow and Govan . . | 2¼ | miles | double line |
| Greenock and Gourock . | 4½ | „ | „ |
| Total . . | 6¾ | „ | „ |

The Govan rail, fig. 32, is of steel, and weighs 60 pounds per yard. The distribution of the material in the rail is less effective for resisting vertical stress than in the Dublin rail; but the thicker section was specially adopted for the transport of railway waggons, besides providing a more massive tread; the section also provided greater thickness under the groove—the weakest point.

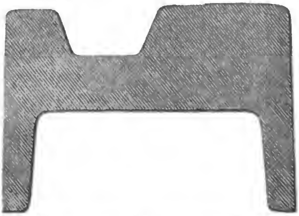


FIG. 32. Vale of Clyde Tramways:—Section of Rail. Scale ½.

The rail is nominally 4 inches wide. It is, in fact, 3⅞ inches wide at the surface, widening downwards to 4 inches at the edges of the flanges, to facilitate the manufacture. The total depth is 2¾ inches. The tread or rolling surface is 1⅞ inches wide, slightly rounded, with a rise of $\frac{1}{16}$ inch. The groove is 1¼ inches wide, with sloping sides and a flat floor, and is only 1/16 inch deep: adapted by its wideness and shallowness to receive the flanges of the wheels of railway waggons, which, being at least 1 inch in depth, of course take a bearing on the floor of the groove. 'It was rather a violent thing to think of doing,' says Mr. Hopkins, in his evidence before the Select Committee of 1877, 'but the obligation was upon us, and it was the only way we could possibly hit upon; because, if we made the groove in the rail wide enough to receive the ordinary tyre of a railway carriage, it would be too wide for the ordinary traffic of a street.' The ledge at the inner side of the rail is ¾ inch wide at the surface.

The rails were rolled to a length of 24 feet, with 5 per cent. of the total quantity as shorter lengths.

The system of construction consisted of rails laid on longitudinal sleepers, bedded on a foundation of concrete laid for the whole width of the way.

The lines of way, where the way is double, are placed at a distance of 3 feet apart, between the rails. Including the usual outside breadths of 18 inches of pavement, the width of the tramway is made up as follows:—

VALE OF CLYDE TRAMWAYS.

| | Feet | Inches |
|---|---|---|
| Two lines of way, 4 feet 7¾ inches gauge | 9 | 3½ |
| Interspace between lines . . . . | 3 | 0 |
| Two breadths of pavement, 18 inches each | 3 | 0 |
| Four widths of rolling surface of rails, 1⅞ inches × 4 = . . . . . . | 0 | 7½ |
| Total width . . . . | 15 | 11 |

In a single line, the total width amounts to 8 feet ¼ inch.

The roadway was excavated for the full width of the tramway—16 feet for a double line—to a uniform depth of 13 inches below the permanent surface. At junctions and crossings, where cross sleepers were laid, the depth was increased to 17 inches, to make room for the sleepers. At places where the excavated bottom was not firm or solid, deeper excavations were made, and filled with hard materials or with concrete. A foundation of concrete made with Portland cement, was laid, 6 inches thick, in the bottom, for the whole of the width. The concrete was of the following proportions:—

| | Parts |
|---|---|
| Portland cement | 1 |
| Ballast | 7 |
| | 8 |

The cement was to be of the best quality, weighing at least 110 pounds per striked bushel, and of such a fineness that 40 per cent. of it would pass through a hair-sieve of 50-gauge. It was to support a tensile stress of 200 lbs. per square inch, one week after having been gauged neat, and kept immersed in water.

The ballast was to be clean and sharp, in the proportion of 6 parts of gravel, broken stone, or screened macadam, to 2 of clean sharp sand.

The ground was, in dry weather, to be well watered before the concrete was filled in.

The longitudinal sleepers were of best Memel timber, 6 inches deep, 4 inches wide, sawn true and square, in lengths of not less than 20 feet, rebated to fit the rails. They were laid on the foundation of concrete. On curves having a radius less than

200 feet, the sleepers could be of shorter lengths, and were sawn to suit the curves. Cross sleepers of the same timber, 6 inches wide and 4 inches deep, at least 7 feet in length, were laid under the longitudinals to support them, at intervals not exceeding 4 feet between centres, at the points and crossings. A foundation of concrete, 6 inches thick, was laid for the support of the cross sleepers. The timber was to be creosoted with creosote oil, having a specific gravity not exceeding 0·95, to the extent of 10 pounds of oil per cubic foot of timber.

The rails were so laid that they extended to the right and the left of the joints of the sleepers. For curves of less than 20 chains radius, the rails were to be bent to the true curve by a proper machine. Swaging or bending by blows was not permitted. Before the paving was laid, the rails were straightened and surfaced. The rails and sleepers were forced together by means of cramps, before the fastenings were driven. The cramps were used for each hole, and were screwed up as near to the fastenings as possible.

The longitudinal sleepers were laid in pairs, and the ends were cut true and square. As in the Liverpool line, they were tied together, except where cross sleepers were used, at every joint, and at intervals of from 4 feet to 5 feet, with wrought-iron tie-bars, 2 inches deep by ⅜ inch thick, having dovetail ends, made of best merchant iron. These are let into dovetail grooves in cast-iron clip-chairs, fitted tightly upon the longitudinal sleepers, and nailed to them with ⅜-inch nails, 2½ inches long. The cross sleepers used at the points and crossings are united to, and act as ties for, the longitudinal sleepers, by two pairs of cast-iron brackets, each longitudinal sleeper being lodged between the brackets of each pair, and fixed to them with ½-inch spikes, 3¾ inches long, chisel-pointed and round-headed, four spikes for each bracket. The joints of the rails are supported by joint-plates of best merchant wrought iron, ⅜ inch thick, 3 inches wide, and 8 inches long, rounded at the angles, and let flush into the longitudinal sleepers.

The fastenings for the rails were double-kneed staples, having 8 inches of total length, made of iron ⅜ inch thick and ⅝ inch wide. The upper part, to pass through holes in the flanges of the rail, was forged round and chisel-pointed; the lower part was jagged, and was driven into the sleepers. Each rail of 24 feet in length was fastened with 23 staples, applied to each side alternately; two pairs of them were applied near the end of each rail.

The staples and the other fastenings employed in the chairs, brackets, points, &c., were made of Lowmoor iron.

After the rails and the sleepers were secured to each other they were raised to the proper level by means of folding wedges, and were truly surfaced and straightened. They were closely and completely packed with concrete underneath over the whole surface. The concrete was finer and stronger than that which was employed for the formation, and was of the following composition:—

| | Parts |
|---|---|
| Portland cement . . . . . . . | 1 |
| Clean coarse sand . . . . . . . | 4 |
| | 5 |

The points and crossings were made of cast iron, of which the whole of the upper surfaces were chilled to a depth of at least $\frac{3}{8}$ inch. Movable tongues were made of cast steel.

The whole of the spaces between the rails, with the 18-inch breadths at the outer sides, were paved with the best whinstone causeway sets, from $3\frac{1}{2}$ to 4 inches wide, and 6 inches deep, laid on a bed of good sharp sand, 1 inch thick. All the sets were to be dressed true and square, and free from cracks, chips, rounded or broken angles, or hollows in the sides. The paving was laid in straight parallel courses across the way, bordered at each side with a longitudinal course of sets 3 inches wide, upon which the macadam of the common roadway abutted. When the stones came in contact with the chairs and the brackets, they were to be carefully cut with a chisel by a mason to fit the work—not to be broken with a hammer.

The sides of the roads next the tramways were made up with broken granite or whinstone. The paving was well rammed, and the joints were partly filled with coarse dry gravel, run with best British asphalte, and covered with sand. The upper surface of the paving finished flush with the surface of the rails.

# CHAPTER VIII.

## RECONSTRUCTION OF THE NORTH METROPOLITAN TRAMWAYS—PARTICULARS OF COST OF LONDON TRAMWAYS.

THE system of construction of the Vale of Clyde Tramways, which has just been illustrated and described, is typical of what Mr. Hopkins' general practice has been until within the last year or two. In the work of reconstructing the North Metropolitan Tramways, now in progress (1877), he has abandoned the cast-iron chairs or clips, with the dovetailed cross tie-bars, for connecting the rails, and has substituted a tie-bar, fig. 33, of the same scantling as before, formed with a ¾-inch bolt at each end, which is passed through each longitudinal sleeper, and screwed up with a shallow nut outside. The tie-bar is brought up with a square shoulder, on a washer, to the inside of each sleeper; the nut is only ¼ inch thick, to minimise the projection, and consequent interference with paving, at the other side of the sleeper. The existing foundation is partly renewed by the excavation, under each sleeper, of a shallow trough in the concrete, 1½ inches deep and 6 or 7 inches wide. This trough is filled with fine concrete, in which the longitudinal sleepers are imbedded to a depth of half an inch. The sleepers are 4 inches wide and 5 inches deep, rebated to fit the rails; they are bedded at their joints on plates of fir, 8 inches wide and 2 inches thick, let into the foundation. The rails are of steel, weighing 60 pounds per yard. They are $3\frac{7}{8}$ inches wide at the surface, $2\frac{3}{4}$ inches deep over the flanges, and $1\frac{5}{16}$ inches thick. They resemble, in section, the Vale of Clyde rail; they have the same total depth, but they are not so thick as the other rail. The groove is $1\frac{1}{4}$ inches wide and $\frac{3}{4}$ inch deep, leaving only $\frac{9}{16}$ inch of metal below the groove. The tread is 2 inches wide, and it is very slightly rounded. The flanges are $\frac{3}{8}$ inch thick at the edge. Each rail of 24 feet in length is fastened by 25 staples, placed at a pitch of 2 feet 7 inches at each side, except those at the ends, where there are

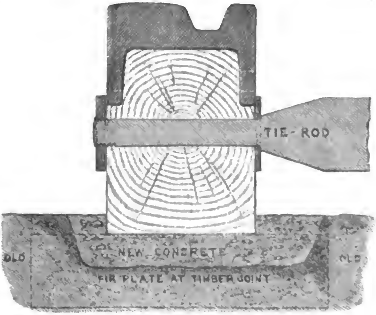


FIG. 33. North Metropolitan Tramways:—Method of Reconstruction. Scale, $\frac{1}{4}$.

two pairs of staples, of which one pair is distant 1½ inches from the end of the rail, and the second pair is 3 inches further off.

Mr. Huntingdon[1] gives particulars of the contractor's charge for constructing the way of the London Tramways, from data obtained by him three or four years ago. They may be taken as approximate costs for London tramways. The gauge of the way is 4 feet 8½ inches; the interspace between the lines is 4 feet. The rails were fixed with staples on kyanised longitudinal sleepers, 21 feet long, with four transverse sleepers, bolted with ¾-inch bolts and nuts to the gauge. The staples were ⅝ inch in diameter. The fish-plates at the joints were 9 inches long and ⅜ inch thick, let into the longitudinal sleepers. The sleepers were bedded in Portland-cement concrete, 6 inches deep, upon which the paving was laid.

London Tramways.—Single Line.

| | Per yard *s.* | *d.* |
|---|---|---|
| Rails, 50 lbs. per yard, ties, spikes, bolts, staples, fishes, &c.; rails at £10. 10*s.*, delivered . . . . . . . . | 10 | 6 |
| Timber creosoted and shaped . . . . | 2 | 0 |
| Fixing and laying, including crossings . | 1 | 0 |
| Maintenance for one year . . . . . | 0 | 6 |
| Contingencies, cartage, lights, watching, waste, and cutting . . . . . | 1 | 6 |
| Risk and profits, 10 per cent. . . . . | 1 | 6 |
| Total . . . . . . | 17 | 0 |

1,760 yards at 17*s.* = £1,496, say £1,500 per mile.

---

[1] *Proceedings of the Institution of Civil Engineers,* vol. l. 1877, page 28, in the discussion of Mr. Robinson Souttar's Paper on 'Street Tramways.'

The cost for paving with granite stones, 7 inches deep, for a double road, with concrete bottom, was as follows:—

DOUBLE LINE.

| | Per square yard *s.* | *d.* |
|---|---|---|
| Granite paving sets 7 inches deep, to tramways 18 feet wide, materials and labour | 11 | 0 |
| Concrete, averaging 6 inches deep, including excavation and removal of road . . | 1 | 6 |
| Contingencies, grouting, carting, watching, removing materials, and sanding . . | 1 | 0 |
| Maintenance for one year . . . . . | 0 | 3 |
| Risk and profit, 10 per cent. . . . . | 1 | 3 |
| Total . . . . . . | 15 | 0 |

1,760 yards × 6 yards × 15*s.* = £7,920, say £8,000 per mile.

The cost for paving, single line, is half the above-given amount, or £4,000; and the total cost of the tramway is made up thus:—

| | Per mile |
|---|---|
| Way . . . . . . . . | £1,500 |
| Paving . . . . . . . . | 4,000 |
| Per mile, single line . . | £5,500 |

or £11,000 per mile, double line.

Extra works, crossings, and sidings are not included in these estimates.

*Inclines and Curves on Tramways in London.*—The steepest gradient of considerable length on the North Metropolitan system, is one in the City Road, of about 1 in 40, on the approach to the 'Angel' at Islington. There are short pieces at the crossings of canal-bridges of about 1 in 25. The curves are of 40 feet radius; with reverse curves of 50 feet radius.

On the London Street Tramways the gradients are easy, excepting a short piece of 1 in 23. The quickest curves have a radius of 30 feet.

On the London Tramways the prevailing gradient is 1 in 50, but there are gradients of 1 in 30.

## CHAPTER IX.

### IRON WAYS: — LIVESEY'S — COCKBURN-MUIR'S — KINCAID'S — DOWSON'S — SCHENK'S.

---

### LIVESEY'S IRON WAY.

MR. JAMES LIVESEY, so early as in 1869, advocated the use of an iron substructure for tramways, constructed on the principle of modern railways, with intermittent bearings: substituting for the continuous wood-sleeper system, with the objectionable vertical spike-fastenings then in vogue, a rail of sufficient stiffness supported on, and solidly and simply fixed to, cast-iron bearings or stools at intervals. In his patents of that year he showed several varieties of iron and steel tramway, of which two kinds, shown in figs. 34 to 37, were laid to a gauge of 4 feet 8½ inches, in the City of Buenos Ayres, the first section having been opened in October 1870.

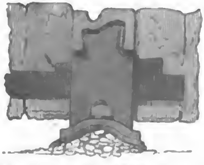


FIG. 34. Buenos Ayres Tramways:—Livesey's Steel Rail System. Scale, ⅛.

The steel groove-rail, figs. 34 to 36, was employed for the city lines. It weighed 40 pounds per yard, and it was rolled in lengths of 24 feet. It is $3\frac{1}{2}$ inches wide, and $2\frac{3}{8}$ inches deep at the rolling side, being formed with deep flanges, so as to derive the practical maximum of strength for a given quantity of material. The tread is $1\frac{3}{4}$ inches wide; the groove is $1\frac{3}{8}$ inches wide, and $\frac{11}{16}$ inch deep. The width of the groove is more than is usual in English tramways, but the width is not inconveniently great, as the narrowest wheel-tyres of common-road vehicles at Buenos Ayres are 3 inches in width. The least thickness under the tread is $\frac{3}{4}$ inch, and at the sides, $\frac{7}{16}$ inch.

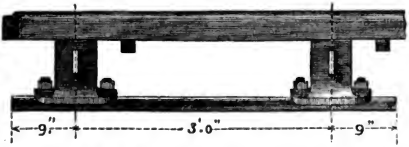


FIG. 35. Buenos Ayres Tramways:—Livesey's Steel Rail System. Scale, $\frac{1}{20}$.

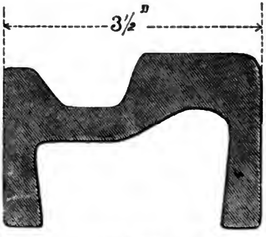


FIG. 36. Livesey's Steel Rail. Scale, $\frac{1}{2}$.

The rails are laid on stools, which are placed at distances of 3 feet apart between the centres; except at the joints of the rails, where an extra stool is placed under the joint. The stools are bolted to base-plates of wrought iron, corrugated: two stools to each base-plate, except at the joint, where there are three stools on the base-plate. The base-plates are 4 feet 6 inches in length, 5½ inches wide, and ¼ inch thick. The stools are each 3½ inches long, and afford a bearing of that length for the rail. The rail is rolled so as to form a dovetail with the stool, and by means of wedge-shaped keys it is held firmly down. At the joint, the rails are fixed to the chair by two wedge-headed bolts and nuts. The sides of the rails are flush with those of the stools, and together they offer vertical walls for the close abutment of the pavement. Mr. Livesey is of opinion that in dealing with such hard and rigid materials, wrought-iron is preferable to cast-iron as a material for the base; and that, on the contrary, cast-iron is preferable to wrought-iron for the standards or stools, since the greater mass of cast-iron absorbs the blows of the traffic, and does not impart, like wrought-iron, a tremulous movement to vehicles. The rails are tied to gauge by wrought-iron tie-bars, 1½ inches deep and ⅜ inch thick, at distances of 3 feet apart. They pass through the stools, and are notched to fit into them, and keyed into position.

The quantities and the costs at current prices, (July 1877), are as follows:—

Livesey's Grooved-rail Tramway, per Mile, Single Line.

| | Tons. |
|---|---|
| 440 lengths of steel grooved rails, 24 feet long, at 40 lbs. per yard, | 63 |
| 440 × 4 = 1,760 wrought-iron base-plates, 22½ lbs. each, | 17·75 |
| 440 × 8 = 3,520 cast-iron stools, 9½ lbs. each . | 18 |
| 440 „ „ joints, 15 lbs. each. | |
| 440 × 4 = 1,760 wrought-iron tie-bars, 10¼ lbs. each, | 8 |
| 1,760 × 2 = 3,520 cotters, 6 oz. each | 0·60 |
| 3,520 + 440 = 3,960 × 2 = 7,920 base-bolts, 7 oz. each | 1·60 |
| 3,520 wrought-iron bent keys, 1¼ lb. each | 2 |
| 440 × 2 = 880 wrought-iron joint bolts, 1 lb. each, | 0·40 |
| Total weight per mile, single line . | 111·35 |

Taken at £9 per ton, in the gross, the cost for the material amounts to £1,002 per mile.

The tramways which have been made with timber substructures, in Buenos Ayres, are being taken up and replaced by iron tramways.

The second kind of tramway, fig. 37, used in the suburban districts of Buenos Ayres, has a flanged or Vignoles rail, such as is used on railways, except that it is rolled with the flange narrower at one side than at the other, to admit of the paving-sets at the outer side being laid close to the head of the rail. The extra width of flange at the inner side, determines the width of the groove in the pavement for the wheel-flanges, and it acts as abutment for the contiguous paving-sets. The rail is placed on a cast-iron stool, to which it is fixed by a hook-bolt and nut; the stool is bolted

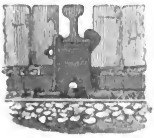


Fig. 37. Buenos Ayres Tramways :—Livesey's Iron Rail System. Scale, ⅛.

to a flat wrought-iron base-plate, which rests on the foundation. The stools are tied to gauge by means of cross-bars and cotters.

There are now nearly one hundred miles of tramways laid on Mr. Livesey's system, in the City of Buenos Ayres. This may be called the City of Tramways, where a tramway runs down nearly every street.

In this connection, it may be noted that Mr. Livesey, in his patent of February 1875, describes a method of maintaining the stone sets in the pavement next the rails, at the same level as the rails. The rail is laid on a longitudinal sleeper, which rests on a 'flat plate sufficiently wide to project under the first row of stones on each side of the rail.'

---

### Cockburn-Muir's Iron Way.

Mr. W. J. Cockburn-Muir patented, in November 1870, a system of iron way, for railways, light railways, and tramways, of simple design, which he calls the 'Block-sleeper' system, in which the rail is supported at regular intervals on cast-iron stools or blocks. It is shown in figs. 38, 39, 40, as employed for tramways. The rails are of wrought-iron, rolled in lengths of 21 feet; they are formed with the ordinary groove on the upper side, and with a vertical web on the under side, to impart to the rails the needful vertical strength between the bearings: they weigh 30 pounds per yard, and are 3 inches in width. The sleepers are cast blocks, rectangular, hollow, open at the base, and ribbed interiorly. They are about 11½ inches long, 7½ inches wide, and 6 inches deep, outside dimensions; and, for ordinary traffic, they are laid at 3 feet 6 inches apart between centres. The span between the sleepers is only 2 feet 6½ inches. They are laid upon the floor of

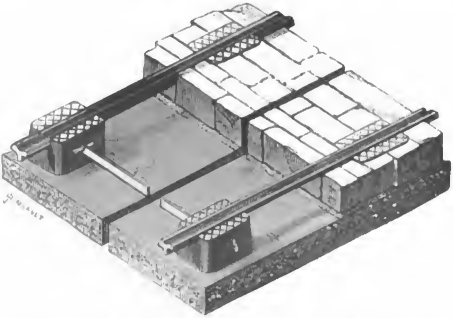


Fig. 38. Cockburn-Muir's Iron Way at Monte Video, &c.

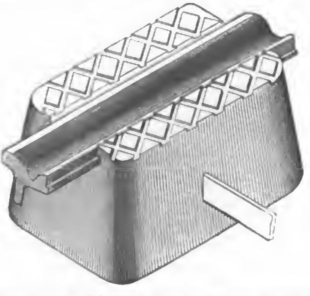


Fig. 39. Cockburn-Muir's Iron Way:—View of sleeper and rail.

the excavation, or upon a prepared bed of concrete. In laying, they are turned upside down, filled with gravel or coarse sand, and closed with a hand-board, then returned into place when the board is slipped out. The weight of each block is from 43½ to 48 pounds, according to the nature of the traffic. The blocks are chequered on the upper surface to give foothold; they act as paving sets, and become integral portions of the paving of the streets. As the sleepers alternate with stone sets next the rails at each side, the formation of ruts or furrows at the sides of the rails is prevented.

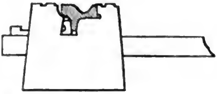


FIG. 40. Cockburn Muir's Iron Way:—Rail, sleeper, and fastenings. Scale, $\frac{1}{12}$.

The rails are rolled with a fillet on the outer side, to fit into a corresponding groove in the recess of the blocks. The recess is formed to receive the rail, which fits it exactly, except at the outer side of the rail, where a key or wedge of cast iron, 13 inches long, is driven, taking a bearing for the whole length of the block, and fixing the rail to the block. As the rail rests solidly on the block for its whole length, the key also acts as a fish at the joints of the rails, and the actual span of the rail is reduced to the distance between the sleepers, or 2 feet 6½ inches.

The sleepers are connected transversely, and tied to gauge, by wrought-iron bars, which are passed right through the blocks, into which they are keyed at the outer side.

The depth of the sleepers affords space for a ½-inch bed of sand, and paving-sets 5½ inches deep.

Mr. Cockburn-Muir's system has been adopted for all the tramways at Monte Video. It is also in use at Buenos Ayres, Salto and Bahia, and short lengths have been laid at Vienna and at Palermo. At Monte Video, the gauge of one of the lines is 4 feet 10⅝ inches, and that of all the others is 4 feet 8½ inches. At Bahia, one part of the line is laid to a gauge of 4 feet 8 inches, and another part to a gauge of 2 feet 5½ inches. At other places, this system has been adopted on a gauge of 4 feet 8½ inches.

The quantities of iron per single mile of 4 feet 8½ inches gauge, are as follows :—

W. J. COCKBURN-MUIR'S TRAMWAY, PER MILE, SINGLE LINE.

| | t. | c. | q. |
|---|---|---|---|
| Rails, wrought-iron, at 30 lbs. per yard. | 47 | 3 | 0 |
| 830 tie-bars, at 7¼ lbs. each | 2 | 13 | 3 |
| 1,660 cotters for tie-bars, at 0·15 lb. each | 0 | 2 | 1 |
| 3,018 block sleepers, at 43½ lbs. each | 58 | 12 | 1 |
| 3,018 wedge keys, at 2½ lbs. each | 3 | 7 | 2 |
| Total weight | 111 | 18 | 3 |

The cost of the materials complete amounts at present (1877) to about £870 per mile, single line.

Portions of Mr. Cockburn-Muir's rail, weighing 30 pounds per yard, are tested regularly by Mr. Kirkaldy, as the rolling proceeds, for transverse strength, at the rate of one sample for every 100 rails. The test-rails are laid on a span of 2 feet 6½ inches between the supports, and they are tested by loads applied at the middle. The following are average results of tests of ten specimens of rail:—

| | | |
|---|---|---|
| Total load applied | 5,000 lb. or 2·23 tons | 6,800 lb. or 3·03 tons. |
| Deflection | ·16 inch | ·60 inch. |
| Set | ·01 inch | ·41 inch. |
| Elastic limit of load | | 5,200 lb. or 2·32 tons. |
| Ultimate load applied | | 9,073 lb. or 4·05 tons. |

All the specimens were removed unbroken. Mr. Cockburn-Muir states that the greatest weight which, in practice, comes upon the rail, does not exceed 3,500 pounds, or 1·12 tons. This is just about half of the elastic strength of the rail.

### Ransomes, Deas, and Rapier's Iron Way.

This system—a cast-iron way laid on concrete—is noticed in this place for the sake of historical sequence. It was patented in December 1869, and a tramway on this system was laid, in 1870, at Glasgow Harbour. It is fully described in Chapter IX.

### Kincaid's Iron Way.

Mr. Joseph Kincaid secured his first patent in March 1872, for his system, in the forms illustrated by figs. 41 to 43; of which figs. 41 and 42 show rails of the ordinary construction at that period, 'supported at suitable distances apart upon supports formed with a flat base, and having an open space in the centre. From the base, the support for the rail rises, having an open space or passage through it, in order that the concrete, in which the support is imbedded, may enclose and surround it, so that it may be solidly imbedded

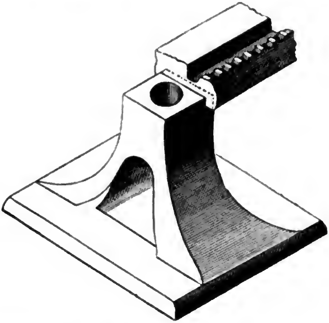


Fig. 41. Kincaid's Iron Way, as patented.

therein.' The rail was fixed to the chair by a vertical spike through the groove, driven into a hardwood plug, which was previously forced into a round hole in the top of the stool or support. As an

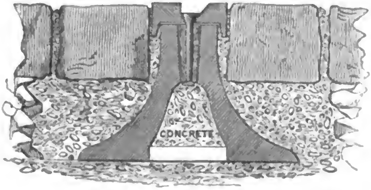


Fig. 42. Kincaid's Iron Way, as patented.

alternative method of attachment, the rail might be fixed to the stool by side-fastenings consisting of spikes driven through holes in lateral flanges of the rail, made sufficiently deep, into plugs imbedded horizontally in the head of the stool.

Mr. Kincaid showed also a method of fixing rails of **T** section, fig. 43, consisting of an uppe table with a vertical flange or web, which was let into a slot in the head of the stool, and fixed there by a horizontal taper cotter.

His first experiment was made on a piece of the Headingley branch of the Leeds Tramways, a quarter of a mile in length, which was laid with the rail, 47½ pounds per yard, fixed to cast-iron stools at 3 feet centres.

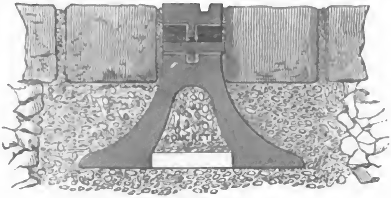


FIG. 43. Kincaid's Iron Way, as patented.

In the design of the first portion of the Sheffield Tramways—the line to Attercliffe—which was opened in October 1873, on his iron system, Mr. Kincaid employed a rail weighing 50 pounds per yard. It had 2½ pounds per yard more metal than the experimental rail at Leeds, and was of a much better section, having lateral flanges 1¼ inches deep. Supported on cast-iron bearings 3 feet apart, the rail was found to be sufficiently strong and stiff. The paving, 5 inches deep, was laid on a bed of ashes 3 inches deep, and was grouted with an asphaltic composition—pitch and tar. In excavating for the work, the ground was first removed to a uniform depth of 8 inches for the whole width of the way, and holes were dug to receive the foundations of concrete and the stools for supporting the rails. The groove of the rail, it may be remarked, was, by superior order, made only 1 inch wide at the surface. It proved to be too narrow, and it bound the car-wheels on sharp curves.

The Dewsbury, Batley, and Birstal Tramway, for which Mr. Malcolm Paterson and Mr. Gomersall successively were engineers, constructed in 1874–75, was laid on Mr. Kincaid's system, according to his first patent, of 1872. The total length of the line —single line—is 3·325 miles, opened in sections successively as follows:—

| | Miles | |
|---|---|---|
| Dewsbury to Batley . | . 1·325 | ... July 25, 1874. |
| Batley to Carlinghow | . 1 | ... March 25, 1875. |
| Carlinghow to Birstal | . 1 | ... June 23, 1875. |
| | 3·325 | |

There are ten sidings, eight of which are 66 yards long, and two are 55 yards long. The line is on an easy gradient of about 1 in 200, falling all the way, with slight exceptions, from Birstal to Dewsbury.

The rails are of wrought iron, and weigh 41 pounds per yard. They are 3¼ inches wide and 2 inches deep, and are carried on chairs 3 feet apart between centres, to which they are secured by vertical spikes through the bottom of the groove. The chairs were laid in concrete, run in with pitch, and the rails were packed underneath with a concrete composed of small broken stone and pitch.

The paving consisted of Dalbeattie granite sets, of which those laid between the rails were 4-inch cubes, and those laid in the 18-inch breadths outside were 6 inches deep. They were grouted with pitch. The paving was laid on a foundation consisting of a 2-inch layer of broken stone, covered with a 4-inch layer of ashes.

The cost of construction of the first 2¼ miles—from Dewsbury, through Batley, to Carlinghow—in a paved road, amounted to £4,600 per mile; whilst the last mile—from Carlinghow to Birstal—in a macadam road, was constructed, with paving complete, for £4,000.

Mr. Kincaid, in his second patent, of January 1876, introduced several improvements in the details of his iron system of tramway. He widened the body of the stool, or chair, to the same breadth as the rail, flush with it vertically, and thus widened the bearing for the rail by taking in the flanges, and presented an even surface as an abutment for the paving-sets. He employed a rail like that of the Dewsbury line, hollowed out under the tread, and formed the head of the chair to fit into and take a bearing in the hollow. For the vertical plugs and spikes he substituted horizontal plugs in the chair, with staples as side-fastenings for binding the rail to the chair.

One of the most recent applications of Mr. Kincaid's way, at Bristol, is illustrated by Plate III., to be afterwards described.

In the tramways now (October 1877) being laid at Adelaide, New South Wales, Mr. Kincaid applies a cross tie-bar through each pair of joint-chairs, in order to compensate for any want of stiffness that may result from the absence of paving.

---

### Dowson's Iron Way.

Messrs. J. E. & A. Dowson devised a system of iron permanent-way, with continuous bearing, in various forms, patented in 1871, and in March 1873. The Madras Tramways, consisting of 11 miles of single line, to a gauge of 1 metre, opened in 1874, were constructed according to one of the forms patented in 1873, fig. 44. The rail was of wrought iron—an ordinary flat grooved rail. It was laid on a series of cast-iron sleepers, which overlapped laterally at the ends, where they were bolted together, and afforded a continued bearing for the rail. The sleepers were formed with fitting-strips, by which they were levelled to receive the rail, and the fastenings consisted of vertical bolts, with countersunk heads, through the groove of the rail, cottered to the sleepers.

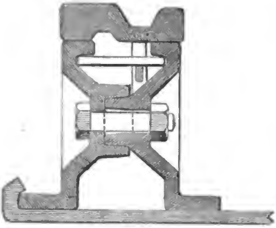


Fig. 44. Dowson's Iron Way.—Madras Tramways. Scale, ¼.

The rails were 1 inch thick and 3¾ inches wide, and they weighed 26 pounds per yard. The sleepers weighed 40 pounds per yard, as laid; they were 2 feet in length, of a flanged form, 4½ inches deep and 2 inches wide. The width of bearing surface on the foundation, which was of concrete, amounted to 4 inches. The sleepers were tied transversely with hook tie-bars at intervals.

Messrs. Dowson have recently matured another and a better form of their system of way, shown in figs. 45 to 47. The sleepers are formed with half-lap ends, and are made up into lengths of 2 feet 6 inches, when laid and bolted together. They are double-flanged, 4 inches wide at the base, 1½ inches wide at the upper surface, and 4½ inches deep. The metal in the body of the casting is about $\frac{7}{16}$ inch thick; in the stiffening flange and the web it is ¼ inch thick. The ends are connected by means of a wrought-iron double-headed clip near the sole; at the upper table, they are formed with bevel edges, which enter corresponding angles in the lower side of the rail. They are forced apart into these recesses by a wrought-

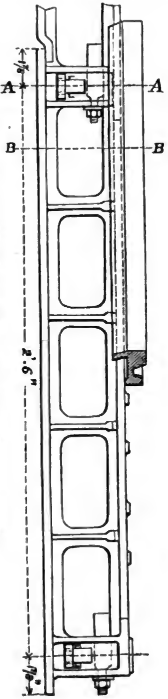


FIG. 45. Dowson's Iron Way.—Improved system. Scale, ⅛.

iron wedge fitted between them, half-way between the top and the bottom, and tightened by a screw-end and a nut. As the wedge is situated midway between the clip below and the rail above, the tightening of the wedge, by which the lap-ends are parted, is resisted simultaneously by the clip and the rails; the rails by the wedge form of the surfaces are drawn down upon the sleepers, and thus a tight fastening of the sleepers to each other, and of the rails to the sleepers, is effected. The sleepers weigh 35 pounds per yard as laid.

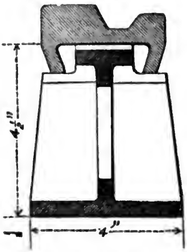


Fig. 46. Dowson's New Iron Way.—Section at B B, fig. 45. Scale, ¼.

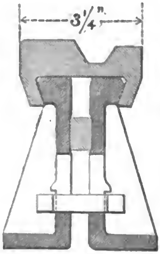


Fig. 47. Dowson's New Iron Way.—Section at A A, fig. 45. Scale, ¼.

The rails are of wrought iron, and weigh 30 pounds per yard; they are 3¼ inches wide and 1 inch thick at the tread. They are formed with two under-flanges, one at each side, ¾ inch deep and ⅜ inch thick, which are inclined inwards in order to clip the ends of the sleepers, as already described. The rails take a continuous bearing on the upper tables of the sleepers, and also by their flanges upon the stiffening ribs of the sleepers, which are formed with flat surfaces to receive the rails. As the flanges are above 2 inches apart, whilst the upper table of the sleeper is only 1½ inches wide, lateral clearance is left between the flanges and the table, for the whole length between the ends of each sleeper, sufficiently wide to admit of the rails being bent to the curves of the line, and at the same time to be laid on straight sleepers. Special castings, therefore, are not required for curves.

Messrs. Dowson supply the following statement of the quantities and cost of their permanent way per mile of single line:—

Dowson's Improved Iron Way, per mile, Single Line.

| Materials | @ | Weight | | | | @ | Cost of materials | | |
|---|---|---|---|---|---|---|---|---|---|
| | lb. | t. | c. | q. | lb. | £ | £ | s. | d. |
| 3,520 yards, wrought-iron rails . . . | 30 | 47 | 3 | 0 | 0 | 8 | 377 | 4 | 0 |
| 3,520 yards, cast-iron sleepers . . . | 35 | 55 | 0 | 0 | 0 | 7 | 385 | 0 | 0 |
| 880 tie-rods, 6 feet apart . . . | 10 | 3 | 18 | 2 | 0 | 13 | 51 | 0 | 6 |
| 4,533 wedges and nuts. | ½ | 1 | 0 | 1 | 0 | 23 | 23 | 5 | 9 |
| 4,533 clips . . . | ¼ | 0 | 10 | 0 | 14 | 23 | 11 | 13 | 0 |
| 4,533 washers . . | — | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 |
| Total . | | 107 | 12 | 3 | 14 | | 849 | 3 | 3 |

## Schenk's Iron Way.

Mr. A. O. Schenk has arranged, and he patented in December 1876, an iron way designed for the operation of mechanical tractive power, fig. 48. It may be classed as a mixed system of iron rails and chairs, and wood sleepers; and consists of two wrought-iron rails of considerable depth, like plates on edge, to provide great vertical stiffness—a bearing-rail and a counter-rail, keyed into double cast-iron chairs by wood keys—and transverse wood sleepers, to which the chairs are spiked. The bearing-rail and the counter-rail are each 5 inches deep, and about 5/16 inch thick in the web. The head of the bearing-rail is only 1½ inches wide and about 1⅜ inches thick; it is rounded at the side, and takes a bearing on the middle of the chair. The head of the counter-rail also stands 1⅜ inches above the chair; it is ⅝ inch thick, and it rests on the head of the chair by a flange which is rolled upon it. The net width of the groove formed by the two rails is ⅞ inch, and the total width of rail-surface, including the groove, is 3 inches. The webs of the rails are not of uniform thickness, but they expand downwards to the lower edge, from a thickness of 5/16 inch to ⅜ inch of thickness. This expansion, amounting to 1/16 inch, for which the chairs are correspondingly overhung, is designed to prevent the rails from rising or tilting off their seats by the action of passing loads:—

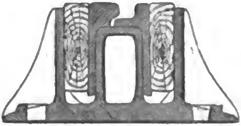


FIG. 48. Schenk's Iron Way. Scale, ⅛.

| | Pounds |
|---|---|
| Weight per yard, bearing-rail . . . . | 27 |
| " " counter-rail. . . . . | 23 |
| Total weight of rails per yard . | 50 |

The rails are keyed into the cast-iron chairs by hard-wood keys, 1½ inches thick, driven vertically from the surface of the way; the chairs are 12¾ inches long at the sole, and are 6 inches high. The middle portion, or stool, on which the rails take their bearing, is cast hollow. The intermediate chairs weigh 20 pounds each, and the joint chairs 35 pounds each. The chairs are spiked to the sleepers by oak trenails. The sleepers are of timber, creosoted; 9 inches wide, 4½ inches thick, and 7 feet 6 inches long; they are placed 3 feet apart between centres. The section of the bearing-rail lends itself readily to the formation of points and crossings, and of curves in the line.

QUANTITIES PER MILE FOR A SINGLE LINE OF WAY, SCHENK'S SYSTEM.

| | t. | c. | q. | lb. |
|---|---|---|---|---|
| 1,760 yards of rails @ 50 lbs. . | 79 | 0 | 0 | 0 |
| 3,080 chairs @ 20 lbs. each . . | 27 | 10 | 0 | 0 |
| 440 „ „ 35 lbs. „ . . | 6 | 17 | 2 | 0 |
| Weight of iron . . | 113 | 7 | 2 | 0 |

7,920 hard-wood keys.
7,920 trenails.
1,760 sleepers, 7 feet 6 inches × 9 inches × 4½ inches each, creosoted.

The hollow space between the rails, formed as a gutter, of asphalte, may be utilised for draining the track, if it is thought desirable. The continuity of the gutter is provided by the hollow stools of the chairs.

This system has been designed by Mr. Schenk to meet the objections urged against the older systems of tramway laid in England, and to meet the new conditions introduced by the substitution of mechanical power for horse power. Mr. Schenk claims the following advantages for his system:—1st. By employing a rail of the section described, one is obtained rigid enough in itself to do without continuous support. 2nd. Rails or fastenings may be renewed without taking up a single stone. 3rd. No fastening of iron is employed. 4th. The bearing-rail is independent of the guard-rail, and the rails may be renewed independently of each other. 5th. Less rolling surface is exposed than in other systems. 6th. The rails are easily bent for curves. 7th. The track may be drained by the asphalte gutter. 8th. In first cost the system compares favourably with others.

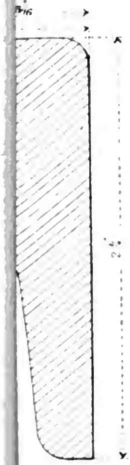
YS IN EDINBUR

EDINBURGH STREET

SCALE

DUNDEE STREET

SCALE



Lockwood and Cº 7. St

# PART II.

## *PRESENT PRACTICE OF TRAMWAY CONSTRUCTION IN THE UNITED KINGDOM.*

## CHAPTER I.

### EDINBURGH STREET TRAMWAYS, 1871–75.

PLATE I.

THE Edinburgh Street Tramways, of which Mr. John Macrae is the engineer, have been entirely constructed on the system of the flat groove-rail, laid on longitudinal sleepers, on a bed of concrete, illustrated in Plate I. The several sections of the line were opened at various dates from 1871 to 1875, as follows:—

| Opened | SECTION | Double line | | Single line | | Total length of streets | |
|---|---|---|---|---|---|---|---|
| | | miles | yards | miles | yards | miles | yards |
| Oct. 1871 | Haymarket and Leith | 3 | 1200 | 0 | 320 | 3 | 1520 |
| Apl. 1872 | Powburn and Newington | 1 | 1630 | — | | 1 | 1630 |
| Nov. 1872 | Morningside and Grange | 3 | 880 | — | | 3 | 880 |
| Dec. 1873 | Newhaven Branch | | 350 | 0 | 1270 | | 1620 |
| May 1875 | Portobello Line | | 770 | 2 | 1590 | 3 | 600 |
| | | 9 | 1310 | 3 | 1420 | 13 | 970 |

The gauge of the way is 4 feet 8½ inches. The way is laid in the middle of the street. For double lines of way, the lines are 9 feet apart between centres, and the total width is 17 feet, contributed thus:—

| For a double line— | Feet | Inches |
|---|---|---|
| Distance apart of centre lines of ways . | 9 | 0 |
| Two half-widths of gauge . . . . | 4 | 8½ |
| Two rolling widths of rail—(1¾ × 2 = ) . | 0 | 3½ |
| Two breadths of 18 inches of paving . | 3 | 0 |
| | 17 | 0 |

| For a single line— | Feet | Inches |
|---|---|---|
| Width of gauge . . . . . . | 4 | 8½ |
| Two half-widths of rail . . . . | 0 | 3½ |
| Two breadths of 18 inches of paving . | 3 | 0 |
| | 8 | 0 |

The gradients of the Edinburgh Street Tramways are unusually severe. The gradients on Leith Walk, which is the worst section, are as follows, commencing at the head of the incline on the level of Princes Street:—

| Gradient | Length. Yards |
|---|---|
| 1 in 22 | 165 |
| 1 „ 14 | 43 |
| 1 „ 50 | 151 |
| 1 „ 24 | 137 |
| 1 „ 20 | 110 |
| 1 „ 24 | 71 |
| 1 „ 23 | 54 |
| 1 „ 29 | 166 |
| 1 „ 35 | 272 |
| 1 „ 42 | 100 |
| 1 „ 52 | 244 |
| 1 „ 43 | 218 |
| 1 „ 38 | 139 |
| Average 1 in 32 | Total length 1,870 yards,<br>Or 1 mile 110 yards. |

The radius of the curve on the incline at the head of Leith Walk, is 47 feet 8 inches, measured to the innermost rail.

The incline on the North Bridge is 1 in 17 for a length of 184 yards.

The average inclination on the Portobello Road is 1 in 30, for 1,500 yards. The steepest incline is 1 in 24 for 200 yards.

The following are particulars of the construction and cost of works recently constructed on the Portobello Branch. The contract was let in July 1874.

The contractor lifted the existing pavement or causeway, and at those portions of the street where the causeway-bed was bad, or which were macadamised, the ground was excavated to a uniform depth, reckoned at 13½ inches below the intended permanent surface, for a width of 17 feet for a double line, and 8 feet for a single line. The actual depth of excavation was less than 13½ inches, for the level of the renewed roadway was raised considerably.

A firm bottom was provided for the concrete. The normal thickness of the bed of concrete, laid on the bottom of the excavation, was 6 inches; a greater thickness was laid where it was necessary. But, where the macadam of the existing macadamised roads was firm enough to form a foundation for the sleeper and the pavement, the surface was dressed and finished, when excavated, to a uniform level, to receive a thin coat of concrete. The concrete was carefully beaten, and the surface formed parallel to the surface of the street. The composition was as follows :—

| | Measures |
|---|---|
| Best Arden lime . . . . . . . | 2 |
| Clean whinstone, broken to a size that will pass through a 2-inch ring . . . . | 4 |
| Quarter-inch Fisherrow or whinstone gravel . | 1 |
| | 7 |

The sleepers are of red Baltic fir, from Riga, or of pitch pine, 4 inches wide and 5 inches deep; rabbetted at the upper corners to receive the fillets of the rails. The joints of the sleepers rest in cast-iron chairs, 6 inches long, the soles of which are let into the lower sides of the sleepers, to present a flush surface to the concrete bed. The sleepers are creosoted with the best creosote, to the extent of 10 pounds per cubic foot of timber, under a pressure of 200 pounds per square inch.

The sleepers are tied to gauge, at intervals not exceeding 6 feet, by tie-bars of wrought iron, 2 inches by $\frac{3}{8}$ inch thick, kneed reversely at the ends, and fixed to each sleeper by a $\frac{5}{8}$-inch bolt, nut, and washer; the rails are fixed to the sleepers by $\frac{5}{8}$-inch bolts, nuts, and washer-plates at the lower side. The bolts are countersunk, and are recessed in the head for a screw-key. All bolt-holes in the wood are filled with Archangel tar, at boiling point, before the bolts are driven. The sleepers are bedded on a $\frac{1}{2}$-inch layer of firm concrete, composed as follows:—

| | Parts |
|---|---|
| Portland cement . . . . . . . | 1 |
| Fisherrow gravel . . . . . . . | 3 |
| | 4 |

mixed and tempered with water.

The rails are of wrought iron, rolled from large piles of the best puddled bars, so arranged that the lower portion of each rail is fibrous, and the rolling surface and upper portion of fine granular iron. The weight is 52 pounds per yard. The rail is 4 inches wide, and 1½ inches thick, having two fillets on the under side, one at each corner, ⅜ inch square. At the upper side, the outer or rolling surface is 1¾ inches wide, and the groove is 1¼ inches wide; the inner ledge is 1 inch wide, and is deeply corrugated, having eighteen corrugations per lineal foot. The depth of the groove is ⅞ inch, leaving a thickness of ⅝ inch under the groove. The width of the groove at the bottom is $\frac{11}{16}$ inch, and the splay of the sides of the groove is the greater towards the inner side of the rail. The standard length of the rails is 21 feet; but a number not exceeding 5 per cent. of the whole quantity might be of less length, in whole numbers of even feet, none of them less than 12 feet long. The variation of length allowed was ¼ inch. The rails are fixed to the sleepers by ⅝-inch bolts at 2 feet centres, except at each end, where the rail is fixed by two bolts at 4½ inch centres, of which the extreme bolt is 1½ inch from the end of the rail. The bolt-holes are made through the bottom of the groove, and the heads of the bolts, when screwed home, are flush with the bottom of the groove.

The ends of the rails are connected by wrought iron fish-plates, 15 inches long, 3 inches wide, and ⅝ inch thick—one plate at each junction, let flush into the sleeper—fixed by the four bolts already mentioned. The holes in the plates are formed oval, being ⅝ inch wide and ⅞ inch long, to allow for slight irregularities. The weight of a fish-plate is 7 pounds.

The points and crossings are of chilled cast iron or other materials.

A thin layer of clean, sharp sand, or ¼-inch Fisherrow or whinstone gravel, may be spread over the concrete, as a packing under the stones to make up for inequalities of surface. But the stones rest direct upon the concrete where the packing was not required.

The causeway or pavement was laid over all the surface between the rails, and for a breadth of 18 inches on each side, beyond the outermost rails. The sets are 3 inches wide, 7 inches deep, and of 10 inches average length, except such as are required to match the neighbouring pavement. They are of new granite or of new whinstone rock, from Westfield, Drumbowie, or Barnton quarries. They are laid dry, hard to hard, or in contact, and grouted with a mixture of equal parts of Portland cement, and ¼-inch Fisherrow gravel, and finished with a coating of fine gravel. Templates were used in laying the pavement. For the purposes of measurement, the width of pavement for a single line of way is taken at 7 feet 4 inches; and, for a double line, 15 feet 8 inches:—exclusive of the width of the rails.

The tramway was to be maintained by the contractor in good order for twelve months after the date of completion. The manufacturer of the rails is to take back and allow a deduction for any rails failing within two years from the date of manufacture. Payments, subject to deduction for penalties or damages, were to be made monthly, to the extent of 90 per cent. of the value of the work done. The balance was to be paid at the end of six months after the date of completion.

The contract prices for work done in the construction of the Portobello section, in 1874–75, were as follows; together with the schedule of prices for alterations, additions, deductions, or extra work:—

### Edinburgh Street Tramways—Cost for the Construction of the Portobello Section. 1874–75.

*From End of Existing Lines to East End of Waterloo Place.*

Lifting and laying aside present causeway, dressing surface of same; providing and laying bed of concrete; all materials for permanent way; new granite causeway blocks, grouted with cement, and coated with fine gravel; and finishing tramways complete, as specified—

| | | £ | s. | d. | £ | s. | d. |
|---|---|---|---|---|---|---|---|
| Double line, 27 lineal yards, | @ | 6 | 0 | 0 | 162 | 0 | 0 |
| Single line, 130 „ | „ | 3 | 0 | 0 | 390 | 0 | 0 |

*From East End of Waterloo Place to Portobello.*

Excavating macadam, and dressing surface of same; providing and laying bottom, bed of concrete, all materials for permanent way; new Whinstone causeway blocks, grouted with cement, and coated with fine gravel; and finishing tramways complete, as specified—

| | | £ | s. | d. | £ | s. | d. |
|---|---|---|---|---|---|---|---|
| Double line, 633 lineal yards, | @ | 5 | 5 | 0 | 3,323 | 5 | 0 |
| Single line, 5,070 „ | „ | 2 | 12 | 6 | 13,308 | 15 | 0 |
| Providing and laying complete, points and crossings for 17 single-line junctions, including extra for laying permanent way, @ £20 . . . . . . | | | | | 340 | 0 | 0 |
| Restoring gas and water pipes interfered with, or other works injured, and lighting, watching, and temporary fencing . | | | | | — | — | — |
| Preparing estimates, schedules of prices, &c., @ 1 per cent. . . . . . | | | | | 175 | 0 | 0 |
| Total cost . . . . . | | | | | 17,699 | 0 | 0 |
| Maintaining the whole of the works for 12 months after being opened for traffic | | | | | 250 | 0 | 0 |
| Total cost, including one year's maintenance | | | | | 17,949 | 0 | 0 |

The costs, not including points and crossings, may be abstracted as follows—

| | £ | s. | d. | £ | |
|---|---|---|---|---|---|
| 660 yards of double line, | 3,485 | 5 | 0 | or 9,294 | per mile. |
| 5,200 „ single line, | 13,698 | 15 | 0 | or 4,637 | „ |
| 5,860 „ (3·33 miles) | 17,184 | 0 | 0 | or 5,160 | „ |
| 6,520 „ (3·70 miles) equivalent length of single line, cost | | | | 4,644 | „ |

SCHEDULE OF PRICES.

| | s. | d. | |
|---|---|---|---|
| Excavating macadam to the depth required for causeway and concrete, and dressing surface | 2 | 0 | per square yard. |
| Excavating the depth required for concrete, where present causeway is to be lifted | 1 | 0 | „ |
| Dressing and clearing surface of concrete, where the existing concrete bed is allowed to remain | 1 | 0 | „ |
| Providing and laying new bottom bed of lime concrete, 6 inches thick, as specified | 3 | 0 | „ |
| Ditto ditto, substituting cement for Arden lime | 3 | 6 | „ |
| Providing and laying fine bed of cement concrete, from 2 to 3 inches thick, as specified to be under sleepers | 1 | 0 | per lineal yard. |
| Ditto ditto, substituting Arden lime for cement | 0 | 9 | „ |
| Cement grouting, as specified | 1 | 6 | per square yard. |
| Grouting with Arden lime | 1 | 3 | „ |
| Lifting and laying aside present causeway blocks | 1 | 0 | „ |
| Lifting present causeway blocks, dressing and relaying them, including grouting with cement, and coating of fine gravel, as specified | 6 | 0 | „ |

SCHEDULE OF PRICES—*continued.*

| | *s.* | *d.* | |
|---|---|---|---|
| Providing and laying new granite blocks, including grouting with cement, and coating of fine gravel, as specified . . . . . . | 13 | 0 | per square yard |
| Providing and laying new Whinstone blocks, including grouting with cement, and coating of fine gravel, as specified . . . . | 12 | 0 | ,, |
| Wrought iron tramway rails, as specified . . . . . . | £10 | | per ton. |
| | *s.* | *d.* | |
| Cast-iron chairs for ends of sleepers | 7 | 6 | per cwt. |
| Bar iron tie-rods, 2 inches by ⅜ inch | 14 | 0 | ,, |
| Bolts and nuts, for fixing rails to sleepers . . . . . . | 0 | 3 | per lb. |
| Ordinary bolts and nuts . . . . | 0 | 3½ | ,, |
| Fish-plates . . . . . . | 14 | 0 | per cwt. |
| Longitudinal sleepers, as specified . | 0 | 6 | per lineal foot. |
| Providing, laying, and fixing complete, rails, sleepers, chairs, tie-rods, bolts, &c., as specified, single line . . . . . . . . | 20 | 0 | per lineal yard. |
| Ditto ditto, but assuming rails to be provided by the company . | 10 | 0 | ,, |
| Providing and laying chilled cast-iron point-rails . . . . | £5 | | each. |
| Ditto ditto with moveable point | 6 | | ,, |
| Ditto ditto crossings. . . . | 5 | | ,, |
| Extra price for laying in junctions from crossing to point, single line | 3 | 6 | per lineal yard. |
| Ditto ditto cross-over roads from point to point, single line . | 3 | 6 | ,, |

QUANTITIES PER MILE, SINGLE LINE, 8 FEET WIDE, AND COSTS AS PER SCHEDULE RATES.

| Work and materials | Quantities | Rate | Amount | | |
|---|---|---|---|---|---|
| | Square yards | | £ | *s.* | *d.* |
| Excavating macadam and dressing surface of same . . . | 4,693 | 2*s.* | 469 | 6 | 0 |
| Concrete bed, 6 inches thick . . . | 4,693 | 3*s.* | 703 | 19 | 0 |
| | Tons cwts. lbs. | | | | |
| Rails, 52 lbs. per yard | 82 0 0 | £10 per ton | 820 | 0 | 0 |
| Bolts and nuts for rails | 5 3 0 | 3*d.* per lb. | 144 | 4 | 0 |
| Tie-rods . . . | 7 0 0 | £14 per ton | 98 | 0 | 0 |
| Bolts and nuts for tie-rods . . . | 0 7 0 | 3½*d.* per lb. | 11 | 8 | 8 |
| Chairs . . . | 2 13 0 | 7*s.*6*d.* per cwt. | 19 | 17 | 6 |
| Fish-plates . . | 1 12 0 | 14*s.* per cwt. | 22 | 8 | 0 |
| | Lineal feet | | | | |
| Sleepers . . . | 10,560 | 6*d.* | 264 | 0 | 0 |
| | Lineal yards | | | | |
| Cement for sleepers . | 3,520 | 1*s.* | 176 | 0 | 0 |
| | Sq. Yards | | | | |
| Whinstone causeway and grouting . . | 4,520 | 12*s.* | 2,712 | 0 | 0 |
| Total cost per mile, single line . . . | | | 5,441 | 3 | 2 |

The amount of cost per mile thus estimated from the schedule rates, is greater than the actual amount per mile, already stated, according to the contract. The difference is accounted for partly by the fact of a reduction having been made on the amount first made out; and partly by the raising of the level of the road, when the tramway was laid, as a consequence of which the depth and quantity of the excavation, as well as those of the foundation of concrete, were generally less than the normal amounts as specified.

## CHAPTER II.

### DUNDEE STREET TRAMWAYS, 1877.

PLATE I.

THE Commissioners of Police of the Burgh of Dundee contracted, in April 1877, for the construction of 2,346 yards, or $1\frac{1}{3}$ miles, of tramway, double line, to the designs of their Engineer, Mr. William Mackison, C.E., Burgh Surveyor, which was completed in July 1877. The line of tramway passes between Dalhousie Terrace and the General Post Office, along Perth Road, Nethergate, Reform Street, and into Euclid Crescent.

According to the system of construction, which is similar to Mr. Hopkins' plan of 1873, and shown in Plate I., flanged rails are laid on longitudinal beams or sleepers, which rest on a bed of concrete, and they are set to gauge by transverse tie-rods dovetailed into cast-iron chairs. The surface is paved. Two sections of rails and sleepers are employed, smaller and larger, of which the lighter scantling is laid in the contracts, comprising a length of 1,562 yards, between Dalhousie Terrace and South Tay Street, and the heavier scantling is laid thence to the Post Office—a length of 784 yards—the busiest part of the route.

The lines are laid to a gauge of 4 feet 8½ inches, with a clear interspace of 4 feet between the rails. The rolling surfaces of the rails are, for the larger scantling, 1⅞ inch wide; and the paving is laid outside the lines for a width of 18 inches at each side. The total width for the double line of way is 17 feet ½ inch, constituted thus:—

| | Feet | Inches |
|---|---|---|
| 2 lines, 4 feet 8½ inches gauge . . . . | 9 | 5 |
| 1 interspace . . . . . . . . . | 4 | 0 |
| 2 breadths, of 18 inches . . . . . | 3 | 0 |
| 4 rolling surfaces (1⅞ inch × 4 =) . . | 0 | 7½ |
| | 17 | 0½ |

The gradients of the line are as follows, commencing at the Post Office:—

| | | Yards |
|---|---|---|
| 1 in 100 | for a length of | 68 |
| 1 in 451 | „ | 167 |
| 1 in 100 | „ | 200 |
| 1 in 210 | „ | 234 |
| 1 in 50 | „ | 67 |
| 1 in 36 | „ | 48 |
| 1 in 31 | „ | 228 |
| 1 in 47 | „ | 99 |
| 1 in 117 | „ | 132 |
| 1 in 674 | „ | 99 |
| 1 in 133 | „ | 65 |
| 1 in 47 | „ | 98 |
| 1 in 77 | „ | 67 |
| 1 in 133 | „ | 88 |
| 1 in 34 | „ | 166 |
| 1 in 50 | „ | 131 |
| 1 in 121 | „ | 263 |
| 1 in 250 | „ | 126 |
| | | 2,346 |

The gradients do not all fall the same way. There is a difference of level of 76 feet between the two extremities of the tramway—the Post Office being at the lower end.

The roadway was excavated, for the way of 60-pound rails, for a uniform depth of about 14 inches —exactly 13¾ inches—below the permanent level of the road for the whole width of the tramway. The bottom was cleared of soft or otherwise unsuitable material, and levelled and beaten to secure a solid and uniform bottom. Upon the bottom is laid, for the whole width, a foundation of concrete, 6 inches thick, well pounded with a heavy beater. The composition of the concrete is as follows:—

| | Measures |
|---|---|
| Whinstone metal, to a 2-inch gauge, screened with a ¼-inch sieve . . . . . . | 2 |
| Gravel, crushed Whinstone, or broken bricks, to a 1-inch gauge . . . . . . | 2 |
| Clean sharp river sand . . . . . . | 2 |
| Portland cement . . . . . . . | 1 |
| | 7 |

To support the longitudinal sleepers, strips of cement mortar, composed of two parts of sand and one part of Portland cement, are laid on the concrete, 1 inch thick and 7 inches wide, increased to 9 inches wide at the chairs.

The longitudinal sleepers are of red-wood, from Riga, Memel, or St. Petersburg, 4 inches wide, 5 inches deep, rebated for the 60-pound rail; and 3½ inches by 5½ inches for the 34-pound rail. They are at least 21 feet in length for the straight parts; and bent or sawn to curves, in lengths of from 12 feet to 18 feet. The whole of the timber is creosoted to the extent of 10 pounds of creosote per cubic foot. The ends of the sleepers are square-jointed, and rest in cast-iron chairs 6 inches long, placed at intervals of from 4 feet to 5 feet. The chairs are nailed to the sleepers with ⅜-inch chair-nails, 2½ inches long, having chisel-points and cup-heads. Transverse tie-rods of wrought iron, 2 inches by ⅜ inch thick, are dovetailed into the chairs.

The rails are of wrought iron; the lighter and heavier rails weigh respectively 34 pounds and 60 pounds per yard. They are rolled to lengths of 21 feet, except 5 per cent. of the total number, which may be of shorter lengths, but not less than 12 feet long. The 60-pound rails have a width of 4 inches and a thickness of 1⅜ inches; they are 2¾ inches deep over the flanges, these being 1⅜ inches deep, and averaging ⅜ inch thick. The groove is $1\frac{5}{16}$ inches wide and ⅝ inch deep, made with a flat floor, similarly to the Vale of Clyde and the Glasgow rails. The rolling surface of the rail is 1⅞ inches wide; the outer flange is $\frac{13}{16}$ inch wide, and corrugated at the upper surface. The 34-pound rail is 3½ inches wide and 1 inch thick; the groove is ⅝ inch deep, and the thickness of metal under the groove is ⅜ inch. The total depth of the rail is $1\frac{15}{16}$ inch. The rails are fixed to the sleepers by side-fastenings or staples of Lowmoor iron, as shown, of which there are 21 for each 21-feet rail.

The points and crossings are of chilled cast-iron, 2 inches thick, corrugated in correspondence with the rails.

The new pavement consists of Pitrodie whinstone sets, from 3 inches to 4 inches thick, 7 inches deep, and from 6 inches to 11 inches in length, with a granite margin, averaging 6 inches wide, on each side of the rails, for the entire length of the tramway. Old paving sets, when redressed, were not to exceed 4½ inches in thickness, and were not to be less than 6½ inches in depth. The pavement was set on a 2-inch bed of coarse Earn sand, and laid hard-to-hard; it stands, as finished, ¼ inch above the level of the rails, leaving a residual thickness of ¾ inch of sand. The finished surface slopes on each side of the centre line of the tramway at the rate of at least ⅛ inch per foot horizontally. The pavement is grouted with a composition of one part of ground Charleston lime, slaked, and two parts of sharp sand; and the surface is blinded with a layer of coarse river-sand.

The works are to be maintained by the contractor for twelve months after being opened for traffic; except the rails, which are to be maintained good for two years.

Payments were made monthly on the work done, 10 per cent. being reserved as security, 6–10ths of which is paid at the end of twelve months, and 4–10ths two years after completion.

The works were constructed according to the annexed schedule of prices:—

DUNDEE STREET TRAMWAYS:—SCHEDULE OF PRICES, 1877.

| | £ | s. | d. | |
|---|---|---|---|---|
| Lifting and laying aside road metal, including sets in crossings . . . | 0 | 0 | 6 | per square yard |
| Lifting, laying aside, and re-dressing old sets . . . . . . . . | 0 | 1 | 0 | „ |
| Excavation, deposited in the pool, at Magdalen Green, including dressing surface for concrete . . . . | 0 | 2 | 6 | per cubic yard |
| Portland-cement concrete, 6 inches thick . . . . . . . | 1 | 2 | 6 | „ |

DUNDEE STREET TRAMWAYS—*continued.*

| | £ | s. | d. | |
|---|---|---|---|---|
| Portland-cement mortar, 1 inch thick | 0 | 1 | 0 | per square yard |
| Longitudinal sleepers of red-wood (Baltic), 4 inches by 5 inches, in 21-feet lengths, checked for rails, fish-plates, nuts, and chairs, charged with creosote, and bedded:—one sleeper | 0 | 1 | 6 | per lineal yard |
| Do. do. in lengths of from 18 feet to 12 feet, 6 inches by 5 inches, cut to radius, and prepared as above | 0 | 2 | 0 | ,, |
| Cast-iron chairs, weighing 11 lbs. each, bedded | 0 | 7 | 0 | per cwt. |
| Wrought iron fish-plates, 2·3 lbs. each, punched for bolts | 0 | 12 | 6 | ,, |
| Wrought-iron tie-rods, 11·2 lbs. each, | 0 | 12 | 6 | ,, |
| Wrought-iron staples, for side-fastenings | 0 | 17 | 6 | ,, |
| Iron rails, 60 lbs. per yard, punched for side-fastenings, secured to sleepers (£9 16*s.* per ton) | 0 | 5 | 3 | per lineal yard |
| Iron rails, 34 lbs. per yard, prepared as above (£12 7*s.*) per ton | 0 | 3 | 9 | ,, |
| Iron rails at crossings, and curves, bent to radii, all together | 0 | 5 | 0 | ,, |
| Cast-iron points and crossings, secured to sleepers, including patterns | 1 | 10 | 0 | per cwt. |
| Paving with Whinstone sets, from Pitrodie Quarry, bedded on sand | 0 | 9 | 0 | per square yard |
| Paving with re-dressed sets, bedded on sand | 0 | 1 | 0 | ,, |
| Grouting joints of pavement | 0 | 0 | 6 | ,, |
| Blinding pavement with sand | 0 | 0 | 1 | ,, |
| Adjusting and re-instating macadamised roads and crossings, alongside the tramways, between paved margins and channels, with the old materials | 0 | 0 | 2 | per lineal yard |
| Maintenance of works for 12 months, for each of the three sections | 20 | 0 | 0 | |

COST FOR 100 YARDS, SINGLE LINE, WITH 60-LB. RAIL. 1877.

| Work and materials | Quantities | Rates | | | Amounts | | |
|---|---|---|---|---|---|---|---|
| | Square yards | £ | *s.* | *d.* | £ | *s.* | *d.* |
| Lifting and laying aside road metal . . | 283 | 0 | 0 | 6 | 7 | 1 | 6 |
| | Cubic yards | | | | | | |
| Excavation in road metal . . . | 87 | 0 | 2 | 6 | 10 | 17 | 6 |
| Concrete . . . | 47 | 1 | 2 | 6 | 52 | 17 | 6 |
| | Square yards | | | | | | |
| Cement mortar . . | 34 | 0 | 1 | 0 | 1 | 14 | 0 |
| | Lineal yards | | | | | | |
| Longitudinal sleepers . | 200 | 0 | 1 | 6 | 15 | 0 | 0 |
| | Cwt. | | | | | | |
| Cast-iron chairs . . | 13 | 0 | 7 | 0 | 4 | 11 | 0 |
| Tie-rods . . . | 6·6 | 0 | 12 | 6 | 4 | 2 | 6 |
| Staples . . . | 2 | 0 | 17 | 6 | 1 | 15 | 0 |
| Chair nails . . . | ⅛ | 0 | 17 | 6 | 0 | 2 | 11 |
| | Yards | | | | | | |
| Rails, 60 lbs. per yard . | 200 | 0 | 5 | 3 | 52 | 10 | 0 |
| | Cwt. | | | | | | |
| Fish-plates . . . | 0·6 | 0 | 12 | 6 | 0 | 7 | 6 |
| | Square yards | | | | | | |
| Whinstone sets . . | 161 | 0 | 9 | 0 | 72 | 9 | 0 |
| Granite sets (margins) . | 100 | 0 | 13 | 0 | 65 | 0 | 0 |

The cost of the way, exclusive of pavement, amounts to £151 for 100 yards; equivalent to £1. 10*s.* 2½*d.* per lineal yard of single line, or to £2,658 per lineal mile. The cost for paving is £1. 7*s.* 6*d.* per lineal yard, or £2,420 per mile. For way and paving together, the cost is £5,078 per mile, single line, or £10,156 per mile, double line. But, with certain compensations, together with the using-up of such old paving-stones as were serviceable, the total cost was expected not to exceed £13,300 for 1⅓ miles of double way, being at the rate of £9,975 per mile.

# CHAPTER III.

## GLASGOW CORPORATION TRAMWAYS, 1874–75.—SYSTEM OF MESSRS. JOHNSTONES AND RANKINE.

PLATE II.

FOLLOWING up the line of construction adopted in the first contract for tramways, in 1872, described at page 42, the engineers of the Glasgow Corporation Tramways, Messrs. Johnstones and Rankine, introduced several modifications of their early designs in the tramways more recently laid out and constructed in 1874-75. In the course of the construction of the tramways, the work was gradually changed from that described for the first contract, to that which is now to be described, as illustrated in Plate II.

The changes consisted of, first, the substitution of the flanged rail—or box rail—for the flat rail, to admit of side-fastenings.

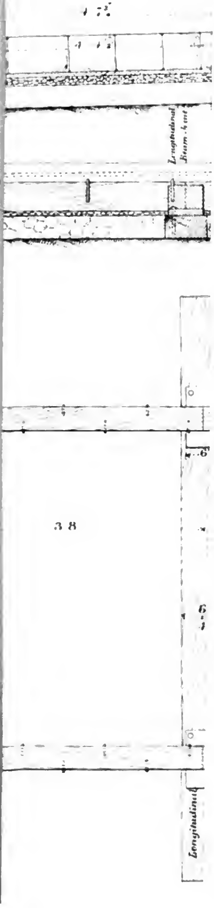
Second, the use of a thinner layer of sand under the paving-stones.

Third, the abandonment of the lower bed of concrete; that is, the concrete under the sleepers.

Fourth, the employment of lime-concrete instead of bituminous concrete.

Fifth, the grouting of the whole of the pavement with bitumen instead of lime.

# CORPORATION TR



The ways are laid to a gauge of 4 feet 7¾ inches, with an interspace of 3 feet 11½ inches between the two lines; whilst the paving was extended for a width of 18 inches at each outer side. The total width for a double line was made up thus:—

| | Feet | Inches |
|---|---|---|
| Two widths of gauge . . . . . | 9 | 3½ |
| Interspace . . . . . . . . | 3 | 11½ |
| Two strips of pavement . . . . . | 3 | 0 |
| Four half-widths of rail (1⅞" × 4 =) . | 0 | 7½ |
| | 16 | 10½ |

For a single line, the total width is 7 feet 11½ inches.

The steepest gradients of the tramways in Glasgow, lie in Renfield Street. Going northwards from St. Vincent Street to Cowcaddens, the gradients are as follows:—

| | | | | | Yards |
|---|---|---|---|---|---|
| | 1 | in | 27 | for | 96 |
| | 1 | " | 21 | " | 113 |
| | 1 | " | 26 | " | 52 |
| | 1 | " | 43 | " | 22 |
| | 1 | " | 81 | " | 88 |
| | 1 | " | 20 | " | 215 |
| Totals | 1 | " | 21 | " | 586 |

The gradients in Great Western Road, west of Kelvin Bridge, Hillhead, are as follows:—

| | | | | | Yards |
|---|---|---|---|---|---|
| | 1 | in | 37 | for | 85 |
| | 1 | " | 27 | " | 110 |
| | 1 | " | 30 | " | 37 |
| | 1 | " | 33 | " | 98 |
| | 1 | " | 41 | " | 85 |
| Totals | 1 | " | 33 | " | 415 |

For a double line, the roadway was excavated to a width of 17 feet; and, for a single line, to a width of

8 feet: to a uniform depth of 12¼ inches below the intended level of the rails. The excavated surface was cleared of all refuse, sludge, loose, or soft material, before the concrete and the sleepers were laid.

The rails were of wrought iron, and weighed 60 pounds per yard; they were rolled in lengths of 24 feet, with about 5 per cent. of the total quantity in shorter lengths. In the character of the section, they are nearly the same as the rails laid in the Vale of Clyde Tramways. They are 3⅞ inches wide and $1\frac{7}{16}$ inches thick; the rolling surface, which is slightly rounded, is 1⅞ inches wide, the groove is 1¼ inches wide, and the flange at the inside is ¾ inch wide. The groove is formed with a flat floor, and is only $\frac{11}{16}$ inch deep, leaving a ¾-inch thickness of metal below it. The lower side flanges are fully ⅜ inch thick and 1⅜ inches deep, thus making a total depth of $2\frac{13}{16}$ inches. Comparing this, the new rail, with the old rail, fig. 25, page 38, whilst the weights of the rails are both 60 pounds per yard, there is a better distribution of metal in the new rail; for whilst it is $\frac{3}{16}$ inch thinner, it is, with the flanges, $\frac{13}{16}$ inch deeper than the first rail. Again, by the comparative flatness and shallowness of the groove, the new rail, though the thinner, retains a sufficient thickness under the groove, which is the weakest part in grooved rails.

The longitudinal sleepers, or beams, are of Baltic red timber, 4 inches wide and 6 inches deep, rebated at each side for the lower flanges of the rail, and not less than 24 feet in length. The joints of the beams are cut square. At curves, the beams are sawn to the radius, and where the radius is less than 80 feet, the length of the beams might be reduced to 14 feet.

The rails were drawn close to the longitudinal beams by means of a powerful cramp, and each rail of 24 feet in length was secured to the beam with side-fastenings, or staples, at each side alternately, and at a pitch of about 13½ inches on each side. Each joint of the rails is fished with an iron plate 8 inches long, 3 inches wide, and ⅜ inch thick, let flush into the upper surface of the beam, and the end of each rail is fixed to the beam by two pairs of staples. Each 24-feet rail is fastened to the beams by a total of 20 staples. The staples are of Lowmoor iron, and are in section ⅜ inch by ⅝ inch; they have a total length of 8 inches, and are forged with two bends, of which the upper bend is chisel-pointed, and passes through holes punched in the flanges of the rails. The lower bend is jagged.

The transverse sleepers are of Baltic red timber, 8 feet long and 4 inches deep; the sleepers at the joints are 7 inches wide, and the intermediate sleepers are 6 inches wide. A joint sleeper is laid under each joint of the longitudinal beams; and, at each joint of the rails, two intermediate sleepers are placed at a distance apart, between centres, of not more than 2 feet. At other places, the distance apart of intermediate sleepers is not more than 3 feet 8 inches between centres. Spike-holes are bored through the sleepers.

All the timber was creosoted to the extent of 10 pounds of creosote per cubic foot.

The longitudinal beams rest in solid cast-iron chairs, 4 inches wide between the flanges, 6 inches wide for the joints of the beams, and 4 inches wide intermediately. The sole of each chair is 9¾ inches long, and rests on the transverse sleeper, which is dressed to receive it; the sole is ¾ inch thick, and the flanges taper from 1 inch thick at the base to ½ inch at the upper edge. The joint-chairs weigh 21 pounds each, and the intermediate chairs 14 pounds each. The chairs are fastened to the sleepers by ⅝-inch wrought-iron spikes, 4 inches long, with cup-heads, and tapered for half an inch of length to ⅜ inch at the ends. The longitudinal beams are fixed in the chairs by ⅝-inch compressed oak-pins, driven through the flanges of the chairs, and through holes bored in the beams; the ends of the pins are sawn off flush with the flanges.

After the sleepers, beams, and rails were accurately laid and adjusted on the bottom of the excavation, the sleepers were packed underneath with fine concrete, composed as follows:—

| | Measures |
|---|---|
| Whinstone shivers, broken to a ½-inch gauge | 3 |
| Sand | 3 |
| Orchard Roman cement | 1 |
| Arden lime | 1 |
| | 8 |

The spaces between the sleepers were filled to the level of the upper surface of the sleepers, by a concrete composed as follows:—

| | Measures |
|---|---|
| Whinstone metal, to a 2-inch gauge, perfectly free from mud, clay, and dirt | 6 |
| Sand | 1 |
| Orchard Roman cement | 1 |
| Arden lime | 1 |
| | 9 |

Upon this bed of concrete, and over the sleepers, a stratum of fine concrete was laid to such a thickness as to bring up the level to half an inch below the paving sets. When the sets were 6½ inches deep, the thickness of the stratum was about 1¼ inches. Upon a ½-inch layer of clean, sharp sand, the paving was bedded. The new paving was to be of granite from the Furness or Bonawe quarries, or, in the option of the Corporation, of Aberdeen granite. It was actually selected and wholly obtained from the Furness and Bonawe quarries. The stones were to be from 3 to 4 inches wide, 6 to 7 inches deep, and 6 to 12 inches in length. They were set in straight and parallel courses across the lines of tramway, abutting closely on the rails, and the sets overlying the chairs were cut to suit them. The surface of the pavement was laid to a slope of ¼ inch per foot transversely, from the centre line of the way. It was grouted with a mixture of British bitumen, manufactured from pure coal-tar pitch, and pitch-oil having a specific gravity of ·95. Oil was to be used in sufficient proportion to produce a plastic grout; the grout was run in hot, and the joints were completely filled with it.

The points and crossings are of cast iron, chilled at the upper side to a depth of at least ⅜ inch.

The improvements in economy and in efficiency realised in the latest practice of the Glasgow Corporation Tramways, with respect to the first system of construction, are very clearly brought out by a comparison of the illustrations. The 4-inch substratum of concrete was dispensed with, for it was found that the bottoms, as excavated, were sufficiently firm and solid to support the cross sleepers. In this way, economy in excavation also was effected, for the depth of material excavated was reduced, by 4 inches, from 16¼ inches to 12¼ inches.

In both the earlier and the later designs, provision was made for rendering the work water-tight, but differently. For, in the first construction, the waterproofing, consisting of the bituminous concrete, was laid at the foundation, and, in the second, it was laid at the surface of the road, consisting of the bituminous-grouted paving.

The adoption, in the later construction, of a thinner layer of sand for paving—½ inch instead of 1¼ inches—was clearly beneficial; it made a steadier pavement, which could be kept better up to the rails, and which demonstrated the advantages of the good foundation.

Finally, the most important improvement consisted in the substitution of the flange-rail with side-fastenings, for the flat groove-rail with a vertical bolt-fastening.

Glasgow Corporation Tramways.—Schedule of Prices.

| | £ | s. | d. | |
|---|---|---|---|---|
| Lifting causeway, excavating and removing stuff from paved roads— | | | | |
| Double line | 0 | 4 | 0 | per lineal yard. |
| Single line | 0 | 2 | 0 | ” |
| Ditto, from macadamised roads— | | | | |
| Double line | 0 | 4 | 0 | ” |
| Single line | 0 | 2 | 0 | ” |
| Furnishing and laying coarse, and also fine, concrete— | | | | |
| Double line | 0 | 11 | 6 | ” |
| Single line | 0 | 5 | 9 | ” |
| Carting, bending, and laying rails, complete— | | | | |
| Double line | 0 | 1 | 9 | ” |
| Single line | 0 | 0 | 11 | ” |

GLASGOW CORPORATION TRAMWAYS—*continued.*

| | £ | *s.* | *d.* | |
|---|---|---|---|---|
| Chairs, laid complete | 7 | 17 | 0 | per ton. |
| Joint plates, ditto | 13 | 10 | 0 | „ |
| Spikes, ditto | 16 | 0 | 0 | „ |
| Rail fastenings, ditto | 44 | 0 | 0 | „ |
| Chilled cast-iron switches, laid complete | 6 | 0 | 0 | each. |
| Ditto, crossings, ditto | 5 | 5 | 0 | „ |
| Transverse sleepers, creosoted and laid— | | | | |
| Intermediate | 0 | 3 | 2 | „ |
| Joint | 0 | 3 | 6 | „ |
| Longitudinal beams, creosoted and laid | 0 | 1 | 11 | per lineal yard. |
| Oak pins. | 0 | 0 | 6½ | each. |
| Furnishing and laying sand— | | | | |
| Double line | 0 | 0 | 9 | per lineal yard. |
| Single line | 0 | 0 | 4½ | „ |
| Redressing and relaying paving stones— | | | | |
| Double line | 0 | 8 | 0 | „ |
| Single line | 0 | 4 | 0 | „ |
| New paving, laid complete— | | | | |
| Double line | 2 | 17 | 0 | „ |
| Single line | 1 | 8 | 6 | „ |
| Pitch-grouting the pavement— | | | | |
| Double line | 0 | 12 | 0 | „ |
| Single line | 0 | 6 | 0 | „ |
| Extra excavation | 0 | 2 | 0 | per cubic yard. |
| Ditto concrete | 0 | 11 | 6 | „ |
| Aberdeen granite for pavement— | | | | |
| Double line | 2 | 16 | 0 | per lineal yard. |
| Single line | 1 | 8 | 0 | „ |

QUANTITIES AND COST PER MILE, SINGLE LINE, OF THE GLASGOW CORPORATION TRAMWAYS, LATEST CONSTRUCTION, 1874–75.

| Work and materials | Per mile | | | | Per lineal yard | | | |
|---|---|---|---|---|---|---|---|---|
| | Quantity | Cost | | | Quantity | Cost | | |
| | | £ | s. | d. | | £ | s. | d. |
| WAY | | | | | | | | |
| Excavation | 1,694 cu. yds. | 176 | 0 | 0 | ·96 cu. yds. | 0 | 2 | 0 |
| Concrete | 630 „ „ | 506 | 0 | 0 | ·36 „ | 0 | 5 | 9 |
| Sleepers | 3,862 cu. feet | 247 | 10 | 0 | 2·20 cu. ft. | 0 | 3 | 0¾ |
| Chairs | 20·62 tons | 161 | 17 | 2 | 26¼ lbs. | 0 | 1 | 10 |
| Spikes | 2,356 lbs. | 16 | 16 | 7 | 1·34 lbs. | 0 | 0 | 2¼ |
| Trenails, oak | 3,528, | 7 | 7 | 0 | 2, | 0 | 0 | 1 |
| Rails | 94·3 tons | 990 | 3 | 0 | 120 lbs. | 0 | 11 | 3 |
| Joint-plates | 1,099 lbs. | 6 | 12 | 6 | ·62 lbs. | 0 | 0 | 0¾ |
| Staples | 11,440 lbs. | 224 | 14 | 0 | 6·5 lbs. | 0 | 2 | 6½ |
| Totals | —— | 2,337 | 0 | 3 | —— | 1 | 6 | 7 |
| PAVEMENT | | | | | | | | |
| Sand | 1,760 lin. yds. | 33 | 0 | 0 | 1 lin. yard | 0 | 0 | 4½ |
| New paving stones | 4,594 sq. yds. | 2,508 | 0 | 0 | 2·61 sq. yds. | 1 | 8 | 6 |
| Pitch-grouting | 1,760 lin. yds. | 528 | 0 | 0 | 1 lin. yard. | 0 | 6 | 0 |
| Total | —— | 3,069 | 0 | 0 | —— | 1 | 14 | 11 |
| SUMMARY | | | | | | | | |
| Way | —— | 2,337 | 0 | 3 | —— | 1 | 6 | 7 |
| Pavement | —— | 3,069 | 0 | 0 | —— | 1 | 14 | 4 |
| Total cost | —— | 5,406 | 0 | 3 | —— | 3 | 1 | 6 |

STOL TRA

d and C° 7 Stanor

# CHAPTER IV.

## BRISTOL TRAMWAYS, LEICESTER TRAMWAYS, SALFORD TRAMWAYS:—KINCAID'S SYSTEM, 1876–77.

### Bristol Tramways. Plate III.

Mr. Kincaid's most recent system of tramway is illustrated in Plate III., which exhibits the construction and details of the Bristol Tramways, laid in 1876. The Hull Street Tramways were constructed on the same system, in the same year; the Leicester tramways in 1874; also, the more lately constructed sections of the Leeds Tramways and the Sheffield Tramways, in the years 1876–77.

The gauge of these lines is 4 feet 8½ inches. The Bristol Tramways are made in single line, 1 mile 1,452 yards in length, with maximum gradients of 1 in 17. The roadway, which was of macadam, was excavated for a width of 8 feet to a uniform depth of 8 inches; and holes for the foundations of the chairs, 3 feet apart between the centres, were excavated to a depth of 15 inches below the surface of the road, 18 inches wide and 16 inches long. The concrete employed was of the following composition:—

| | Parts |
|---|---|
| Clean sharp gravel or broken stone to a 1-inch ring-gauge | 3 |
| Sand | 2 |
| Fresh-burned Aberthaw lime | 1 |
| | 6 |

The holes were filled with concrete to a total height of 8 inches, in which the soles of the chairs were imbedded to a depth of 3 inches below the upper surface of the concrete. Concrete was also applied under each of the rails for its whole width, between the chairs, in some measure affording bearing surface, but designedly to occupy the space under the rail and keep it free from water.

The rails are of wrought iron, rolled from a single ingot of best malleable No. 2 mine iron, weighing 43 pounds per yard, with a margin of from 42 to 44 pounds, in lengths of 24 feet; except five per cent. of the whole number, which were to be of shorter lengths. The rails are $3\frac{1}{2}$ inches wide, and $\frac{9}{16}$ inch thick under the tread and under the groove; they are formed with two flanges, one at each side, $2\frac{5}{16}$ inches deep, slightly taper in thickness, $\frac{7}{16}$ inch thick at the lower edges. The tread of the rail is $1\frac{5}{8}$ inches wide, the groove is $1\frac{3}{8}$ inches wide, and the outer border is $\frac{1}{2}$ inch thick at the edge, and corrugated. The groove is taper in section, and it slopes mostly towards the outside. The tread of the rail is flat, but it is slightly inclined upwards, to the extent of $\frac{1}{16}$ inch rise, towards the centre of the rail. With such a formation, the contact of the car-wheels with the tread is concentrated at the inner edge of the tread; the load is, in consequence, fairly delivered on the rail at the middle of its width and undue twisting action or deflection by side-loading is obviated—a point of special importance for the stability of a suspended rail.

The chairs, of cast iron, have rectangular bases, 14 inches wide, 12 inches long, and ¾ inch thick, at a level 10 inches below the surface of the rails. They are, like the rails, 3½ inches wide at the head; and they give a bearing to the rails 3½ inches long at intermediate points, and 7 inches long at the joints. They are placed 3 feet apart between centres. The rails are fastened to the chairs by staples at each side, made of half-round bar iron, best Staffordshire, which engage into holes punched in the rails, and are driven into hard-wood plugs, which are forced into holes in the heads of the chairs. There are two staples for each end of the rails, at each side, to make the joints; and, for a 24-feet rail, there are 11 staples at each side, or 22 in all. The plug-holes in the chairs are slightly taper; at the larger ends they are 1¾ inches in diameter for the joint-chairs, and 1⅜ inches intermediately.

The points and crossings are of cast iron, with wrought-iron tongues. The upper surfaces were file-dressed. There are three cast-iron chairs to each point, and two to each crossing.

All the castings are of No. 1 strong grey iron.

The paving consists of granite sets, 5 inches deep, laid, for the extreme width of 8 feet, on a bed of gravel 3 inches thick, spread on the bottom of the excavation. The paving was grouted with a liquid mortar, containing six parts of fine sand to one part of fresh-burnt lime; it was rammed before the grouting had set, and was again grouted.

### ACTUAL COST OF THE BRISTOL TRAMWAYS (KINCAID'S WAY), PER MILE, SINGLE LINE, 1876.

| | | @ | | | | |
|---|---|---|---|---|---|---|
| | £ | s. | d. | £ | s. | d. |
| Rolled iron rails, 43 lbs. per yard, 68 tons . . . . | 7 | 10 | 0 | 510 | 0 | 0 |
| Cast-iron chairs, royalty included, 79 tons . . . . . . | 6 | 12 | 9 | 524 | 7 | 3 |
| 4,000 wood plugs, per 1,000 . | 4 | 10 | 0 | 18 | 0 | 0 |
| 9,700 wrought-iron staples, each | 0 | 0 | 2 | 80 | 16 | 8 |
| Laying the way, including excavation and concrete, per lineal yard . . . . . . | 0 | 7 | 0 | 616 | 0 | 0 |
| Total cost of way . | | | | 1,749 | 3 | 11 |
| Providing and laying granite pavement, including gravel bed and grouting, 4,400 square yards . . . . . . | 0 | 12 | 0 | 2,640 | 0 | 0 |
| | | | | 4,389 | 4 | 0 |

The work was to be maintained in good order for six months after it was completed and opened for traffic. Payments were made monthly, less 10 per cent. which was kept in reserve until the contract was completed.

### LEICESTER TRAMWAYS.

In addition to the tramways, 4·44 miles in length, constructed in 1874, the Leicester Tramways Company have (October 1877) contracted for the construction of five miles' additional length of tramway, on Mr. Kincaid's system. The rails are to be rolled of Siemens' steel, weighing 47 pounds per yard. The staples are to be of Lowmoor iron. The following are particulars of the contract:—

### Cost of new line of the Leicester Tramways (Kincaid's Way) per mile, Single Line.

| | | @ | | |
|---|---|---|---|---|
| | £ | s. | d. | £ |
| Rolled Siemens' steel rails, 47 lbs. per yard, 74 tons, delivered | 8 | 7 | 6 | 620 |
| 75 tons, Kincaid's cast-iron chairs | 3 | 18 | 6 | 294 |
| Lowmoor iron fastenings or staples, and plugs | | — | | 100 |
| 5 pairs of cast-steel points | | — | | 50 |
| Laying the way, including excavation for paving as well as for the way and concrete, per lineal yard | 0 | 5 | 1 | 450 |
| Total cost | | | | 1,514 |
| Providing and laying Leicestershire granite paving, 8 feet wide, as follows:—Sets 6 inches × 4 inches outside the rails, and one course next the rails inside; 'Randon granite,' not less than 4 inches deep and 4 inches cube, over the remaining surface, per lineal yard, say, | 0 | 6 | 4 | 1,300 |
| Total cost for way and paving | | | | 2,814 |
| Add, for engineering and legal charges | | | | 186 |
| Total per mile, single line | | | | £3,000 |

---

### Salford Corporation Tramways.

The most recent development of Mr. Kincaid's system is exemplified in the Salford Tramways lately constructed to the plans of Mr. Alfred M. Fowler, the borough engineer and surveyor, illustrated by figs. 49, 50, 51. The details of the rail and the fastening have been specially designed by

Mr. Fowler. The tramways consist of two lines:—a double line, from Albert Bridge to the Pack Horse Inn, 1 mile, 1,437 yards long; and a single line, in Bury New Road, between the Kersal Tollbar and Grove Inn, 1 mile 479 yards long. The roadways were partly paved and partly macadamised.

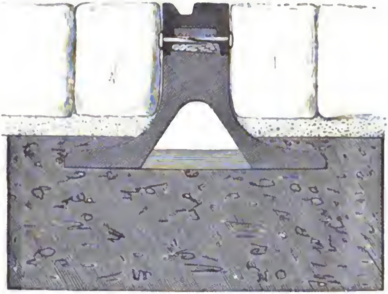


FIG. 49. Salford Corporation Tramways:—Kincaid's system, arranged by Mr. A. M. Fowler. Scale, ⅛.

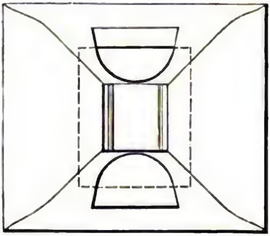


FIG. 50. Salford Corporation Tramways:—Plan of Chair. Scale, ⅛.

The rails are laid to a gauge of 4 feet 8½ inches, with an interspace of 4 feet between the two lines of a double way. The total width for a double way, including the 18-inch breadth at each side, is 17 feet, constituted as follows:—

| | Feet | Inches |
|---|---|---|
| 4 feet 8½ inches × 2 = . . . . . . | 9 | 5 |
| Interspace . . . . . . . . . | 4 | 0 |
| 18 inches × 2 = . . . . . . . | 3 | 0 |
| 4 half-breadths of rail (1¾ × 4 = ) . . . | 0 | 7 |
| | 17 | 0 |

For a single line, the total width is 8 feet.

The pavement is lifted, or the macadam is excavated, for a uniform depth of 8 inches, for the whole width of 17 feet for a double line, or of 8 feet for a single line. Holes for the foundations of the chairs are excavated at 3 feet apart between centres, to a depth of 15 inches below the surface, or level of the rails; they are 18 inches long and 20 inches wide at the bottom.

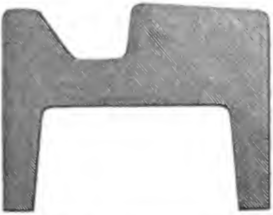


Fig. 51. Salford Corporation Tramways:—Section of Rail. Scale, ½.

The concrete is composed as follows; thoroughly mixed as required, on a wooden platform, and used fresh:—

| | Measures |
|---|---|
| Clean sharp gravel, broken stone, or macadam, to a 1-inch ring-gauge . . . . . | 4 |
| Best Portland cement . . . . . . | 1 |
| | 5 |

The holes excavated for the foundations of the chairs are filled with concrete, in which the chairs are properly bedded and levelled; the concrete is rammed underneath and around each chair. Each block of concrete is 20 inches by 18 inches, by 8 inches deep, and the under-side of the sole of the chair is sunk to a level 1⅝ inches below the upper side of the block. The space under the rails between the chairs is filled with concrete, by enclosing the space at one side of the rail, and ramming in the concrete with wooden beaters from the other side.

The chairs stand at a level 8⅝ inches below the surface of the rail, measured to the under-side of the chair. The sole has an average thickness of 1 inch; the sides have a minimum thickness of ¾ inch; the neck of the intermediate chair is 3½ inches square, whilst the head, which takes the rail, is slightly taper, and is 2½ inches wide. The head is flat on the top, and receives the rail with a flat bearing. The intermediate chairs weigh about 48 pounds each, and the joint-chairs 68 pounds each. The plug-holes in the heads of the chairs are taper, 1 inch in diameter at the larger end; filled with ash plugs.

The rails, of iron, were rolled from piles composed of selected puddle-bars, made from refined mine or pig-iron, granular above, fibrous below; to weigh 50 pounds per yard, and to be rolled to lengths of 24 feet. Five per cent. of the whole number of rails were rolled, as shorter lengths, not less than 12 feet long. Rails weighing less than 50 pounds, or more than 52 pounds, were to be rejected. The rails are 3½ inches wide, and have 2¾ inches of total depth, with a maximum thickness of 1⅜ inches. The tread or rolling surface is 1¾ inches wide; the groove is 1¼ inches wide, and ¾ inch deep; and the outer ledge is ½ inch wide at the surface, deeply corrugated at the rate of fourteen corrugations per foot of length. The surface of the tread is flat and inclined, so that at the centre of the rail it is ⅛ inch higher than at the side. It is thus insured, as was remarked of Mr. Kincaid's Bristol rail, that car-wheels should take their bearing on the middle or centre line of the rail.

In each 24-feet rail 18 holes are drilled, in pairs at 3-feet distances apart, through which the rails are fastened to the chairs by ⅜-inch round wrought-iron spikes, 2¼ inches long from the head, taper for part of their length. The spikes were to be of the very best quality and workmanship, capable of being bent cold to form a right angle, without fracture or flaw. The rails and chairs were pressed together by means of a screw-cramp, while the spikes were being driven; and the spikes were in such a position, near the upper part of the plug-holes, and were so driven that, by their action, the rail was brought well home to the top of the chair. Here, the staple usually employed has been replaced by a direct-acting spike, according to one of the forms described in Mr. Kincaid's patent of 1876. The heads of the spikes are ¼ inch thick, and they project by so much from the sides of the chairs, which otherwise, with the rails, present flat abutments for paving-sets.

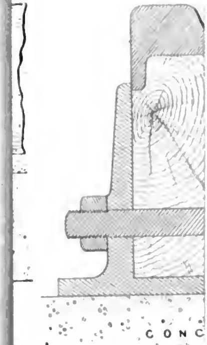
The points are 8 feet long; they are of chilled cast-iron, annealed cast-steel, or of Vickers' forged-steel. The crossings were made by cleanly cutting ordinary rails to the required angle, so as to fit truly to the sides of the rails of the main road to be crossed. The adjoining flanges at the junction are bolted together with ½-inch bolts.

The paving consists of granite sets 6 inches deep, laid on a bed of sand 2 inches thick.

The whole of the work is to be maintained for twelve months after completion; except the rails, which are to be maintained for two years.

The cost of the work, excluding paving, was £1,925 per mile, single line.

# TRAMWAYS AT



SECTION TH
SCA

Crosby Lockwood

# CHAPTER V.

## SOUTHPORT TRAMWAYS, WIRRAL TRAMWAY, BY MR. C. H. BELOE—BELOE'S NEW SYSTEMS.

PLATE IV.

THE Southport Tramways, opened in 1873, of which Mr. Charles H. Beloe is engineer, consist of a single line 4 miles in length, laid with flanged iron rails, fastened to longitudinal sleepers laid on transverse sleepers in concrete, to a gauge of 4 feet 8½ inches, illustrated in Plate IV. The ground was excavated for a width of 8 feet, to a uniform depth of 12½ inches below the surface of the roadway. A foundation of concrete, 3 inches thick, was laid over the whole of the bottom.

The concrete was composed as follows:—

| | Measures |
|---|---|
| Broken stone | 3 |
| Coarse sand, or fine gravel | 1 |
| Blue-Lias lime | 1 |
| | 5 |

Upon this base, cross sleepers of pitch pine, 6 inches wide and 3 inches deep, were laid at intervals of 6 feet between centres. Longitudinal sleepers of the same timber, 3 inches wide and 6 inches deep,

## SOUTHPORT TRAMWAYS:—QUANTITIES AND COSTS FOR ONE MILE, SINGLE WAY, 1873.

| | Quantity | | Rate | £ | s. | d. | £ | s. | d. |
|---|---|---|---|---|---|---|---|---|---|
| Excavation, 8 feet wide:— | | | | | | | | | |
| Macadam, 3 inches deep | 4,693⅓ | square yards | @ 2½*d.* | 48 | 17 | 8½ | | | |
| Below foundation of roads, 9½ inches deep | 1,238 | cubic yards | @ 1*s.* | 61 | 18 | 0 | | | |
| Bottom of excavation levelled | 4,693⅓ | square yards | @ ½*d.* | 9 | 15 | 6½ | | | |
| | | | | | | | 120 | 11 | 3 |
| Concrete, 8 inches deep (1,043 cubic yards); deduct for sleepers 52 cubic yards | 991 | cubic yards | @ 9*s.* | | | | 445 | 19 | 0 |
| Timber:— | | | | | | | | | |
| Longitudinal sleepers, pitch-pine, 6 inches × 3 inches, in 21 feet lengths | 10,560 | lineal feet | @ 5*d.* | 220 | 0 | 0 | | | |
| Cross sleepers, notched, at 6 feet intervals, 7 feet long × 880 = | 6,160 | lineal feet | @ 5*d.* | 128 | 6 | 8 | | | |
| | | | | | | | 348 | 6 | 8 |
| Iron Rails, 21 feet long, 1,760 × 2 = 3,520 yards, at 40 lbs. per yard | say, 63 | tons | @ £13 | | | | 819 | 0 | 0 |
| Staples:— | | | | | | | | | |
| Short, 4 at every joint, 2,008 @ 4 oz. | 4½ | cwt. | @ 24*s.* | 5 | 8 | 0 | | | |
| Long, 4 at every joint 2,008<br>Long, 4 at every yard of way, 7,040<br>9,048 @ 4½ oz. | 23 | cwt. | @ 24*s.* | 27 | 12 | 0 | | | |
| Twisted, 4 at every cross sleeper, except at longitudinal joints—880 cross sleepers, less 251 joints = 629 × 4 = 2,516 @ 5 oz. | 7 | cwt. | @ 24*s.* | 8 | 8 | 0 | | | |
| | | | | | | | 41 | 8 | 0 |
| Brackets, double, 2 at each longitudinal joint; 502 joints × 2 = 1,004 @ 5 lbs. 6 oz. | 48¼ | cwt. | @ 14*s.* | | | | 33 | 15 | 8 |

| | Tons. | Cwt. | | | | |
|---|---|---|---|---|---|---|
| Oak trenails, 6 to each longitudinal joint; 502 joints × 6 = 3,012 | | | | @ £6 per 1,000 | | 18 0 0 |
| Fish-plates, 502 @ 5·86 lbs. | | | 26¼ cwt. | @ 13*s.* | | 17 1 3 |
| Excavation and materials for tramway | | | | | | 1,844 1 10 |
| Paving, 4,400 square yards:— | | | | | | |
| Granite sets @ 6*s.* 2*d.* per square yard<br>Paving @ 4*d.* " "<br>Grout @ 6*d.* " "<br>Sand @ ¼*d.* " " | | | 4,400 square yards | @ 7*s.* 0¼*d.* | | 1,544 11 8 |
| Making good between new and old pavement | | | 1,760 lineal yards | @ 6*d.* | | 44 0 0 |
| Labour, laying tramway | | | 1,760 lineal yards | @ 1*s.* 10*d.* | 161 6 8 | |
| Labour, cutting beds for fish-plates | | | 502 beds | @ 4*d.* | 8 7 4 | |
| | | | | | | 169 14 0 |
| K Carting:— | | | | | | |
| Rails and fish-plates | 64 | 6¼ | | | | |
| Brackets | 2 | 8¼ | | | | |
| Staples | 1 | 15 | | | | |
| Trenails | 0 | 1 | | | | |
| Timber | 38 | 5 | | | | |
| Granite sets | 782 | 0 | | | | |
| Total weight, say | | | 889 tons | @ 1*s.* 6*d.* | | 66 13 6 |
| Watching, lighting, and contingencies | | | | | | say 100 0 0 |
| Total cost | | | | | | 3,769 1 0 |
| Credit:— | | | | | | |
| Old materials | | | | | | say 41 0 0 |
| Net cost | | | | | | 3,728 1 0 |

Say £3,730 per mile.

were laid upon and let 1 inch into the cross sleepers, to which they are secured with four staples at each intersection. At the joints of the longitudinal sleepers, cast-iron brackets are employed to fasten them by spikes to the cross sleepers.

The rails, weighing 40 pounds per yard, are 3 inches wide and 1¼ inches thick; and, with the side flanges, are 2¼ inches deep. The width was limited to 3 inches, as it was thought that a rail of this width would offer less interference with ordinary traffic than a rail of the usual width, 4 inches; besides it costs less in first outlay. The rails are secured to the longitudinals by staples, at intervals of 3 feet on each side of the rails. The joints are secured by two pairs of staples at the end of each rail. A wrought-iron fish-plate, 15 inches by 2¼ inches, and ⅝ inch thick, is placed at the joints.

After the rails and sleepers were adjusted to the street levels, the spaces around the cross sleepers, and for 2 inches above them, were filled with concrete, which was brought to a uniform surface at a level 4½ inches below the surface-level. The cross sleepers thus became enveloped in a mass of concrete 8 inches deep. Upon a ½-inch bed of sand, 4-inch cubical sets were laid, as pavement, and grouted.

The Wirral Tramway (Birkenhead, Tranmere, Rock Ferry, and New Ferry), is a single line, 3 miles in length, including sidings. It was constructed to the designs of Mr. Beloe, as engineer, and was opened in 1877. In the design of this line, 4 feet 8½ inches in gauge, illustrated in Plate IV., the engineer has materially simplified the construction, compared with that of the Southport line. The rails are laid on

### Wirral Tramway:—Quantities and Costs for One Mile, Single Way, 1877.

| | Tons. | Cwt. | | | £ | s. | d. | £ | s. | d. |
|---|---|---|---|---|---|---|---|---|---|---|
| Excavation, 8 feet wide:— | | | | | | | | | | |
| Macadam, 3 inches deep | | | 4,693 square yards | @ 6*d.* | 118 | 0 | 0 | | | |
| Below foundations of roads | | | 668 cubic yards | @ 4*s.* | 134 | 0 | 0 | | | |
| Levelling bottom | | | 4,693 square yards | @ 1*d.* | 20 | 0 | 0 | | | |
| | | | | | | | | 272 | 0 | 0 |
| Concrete | | | 440 cubic yards | @ 9*s.* | | | | 198 | 0 | 0 |
| Timber | | | 2,000 cubic feet | @ 2*s.* 6*d.* | | | | 250 | 0 | 0 |
| Iron rails @ 52 lbs. per yard | | | 84 tons 6 cwt. | @ £8. 10*s.* | | | | 717 | 0 | 0 |
| Staples | | | 15 cwt. | @ £1. 2*s.* 6*d.* | | | | 17 | 0 | 0 |
| Chairs | | | 4 tons 16 cwt. | @ £6 | | | | 29 | 0 | 0 |
| Fish-plates | | | 1 ton 11 cwt. | @ £9 | | | | 14 | 0 | 0 |
| Tie-rods | | | 5 tons 2 cwt. | @ £14 | | | | 71 | 0 | 0 |
| Excavation and materials for tramway | | | | | | | | 1,568 | 0 | 0 |
| Paving:—Granite sets | | | 759 tons | @ £1 8*s.* 6*d.* | 1,082 | 0 | 0 | | | |
| Laying, grout, and sand | | | 4,300 square yards | @ 1*s.* 8¾*d.* | 372 | 0 | 0 | | | |
| | | | | | | | | 1,454 | 0 | 0 |
| Making good between old and new pavements | | | 1,760 lineal yards | @ 5*d.* | | | | 37 | 0 | 0 |
| Labour, laying tramway | | | 1,760 lineal yards | @ 2*s.* 6*d.* | | | | 220 | 0 | 0 |
| Carting:—Rails and fish-plates | 85 | 17 | | | | | | | | |
| Chairs | 4 | 6 | | | | | | | | |
| Staples | 0 | 15 | | | | | | | | |
| Tie-rods | 5 | 2 | | | | | | | | |
| Timber | 30 | 12 | | | | | | | | |
| Granite sets | 759 | 0 | | | | | | | | |
| Total weight, say | | | 886 tons | @ 2*s.* | | | | 80 | 0 | 0 |
| | | | | | Total | | | £3,368 | 0 | 0 |

longitudinal sleepers bedded in concrete, and connected by tie-bars. In the choice of this system of construction, in which tie-bars were substituted for cross sleepers, the engineer was influenced by a desire to leave the already existing foundation undisturbed. The foundation consisted of a stratum of rock-pitching, or rough stones, laid in by hand, 10 inches in depth, and if cross sleepers had been laid, the pitching would have been broken into to such an extent as to have seriously weakened the foundation. But, though the cost was considerably reduced by the use of tie-rods instead of cross sleepers, the engineer has regretted that he did not take out the old pitching, and lay a foundation of concrete for the whole width of the tramway.[1]

The rails are of steel, and are wider and heavier than the Southport rails; they are 4 inches wide, weigh 52 pounds per yard, and are rolled to lengths of 21 feet. They are $1\frac{3}{8}$ inches thick, with side flanges $\frac{15}{16}$ inch deep, making the total depth $2\frac{5}{16}$ inches. In improving upon the Southport rail, Mr. Beloe observed that the latter was not possessed of sufficient stiffness. The rails are bedded on longitudinal sleepers 4 inches wide and 6 inches deep, and are fastened to them by wrought-iron side staples, 10 to each rail, 6 feet apart at each side, except near the joints of the rails, where they are closer to each other.

The ends of the sleepers are lodged in cast-iron chairs 9 inches long, tied together transversely by two $\frac{3}{4}$-inch tie-rods, which take a bearing by collars on the inner sides of the chairs, and pass through the chairs and the sleepers, and are fastened by nuts outside. The sleepers are likewise tied by three intermediate tie-rods passed through and screwed up outside.

---

[1] *Proceedings of the Institution of Civil Engineers*, vol. l. page 41.

The ground was excavated to a uniform depth of 7½ inches below the permanent surface; two longitudinal trenches in addition, 12 inches wide and 3 inches deep, were excavated under the sleepers, where the total depth amounts to about 10½ inches. When the rails and sleepers were adjusted in their places, the whole of the bottom of the excavation, as well as the trenches under the sleepers, were filled with concrete to a height of 3 inches above the bottom:—thus imbedding the sleepers to a depth of 3 inches, and leaving 4½ inches for paving. The paving consists of 4-inch cubes bedded on a ½-inch layer of sand.

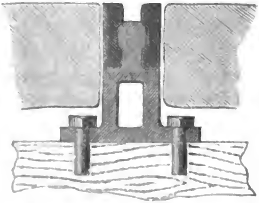


Fig. 52. New double-rail system, by Mr. C. H. Beloe. Scale, $\frac{1}{12}$.

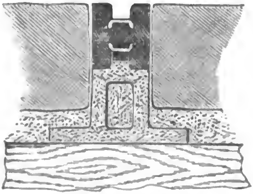


Fig. 53. New double-rail system, by Mr. C. H. Beloe. Scale, $\frac{1}{12}$.

Mr. Beloe has recently patented a system of double-rail—or twin-rail, as it may be called—bolted to cast-iron chairs on cross sleepers, illustrated by figs. 52 to 55. The rails are of steel, weighing each 30 pounds per yard, or, together, 60 pounds per yard.

They are 3½ inches in depth, and each of them 1 inch wide at the rolling surface, with an interspace forming a groove 1 inch wide: making a total width of 3 inches, and a total rolling surface 2 inches wide. The rails are fastened to cast-iron chairs, by means of a ¾-inch right-and-left-handed screw, formed with a four-sided or six-sided head at the middle, between the twin-rails, by which the rails are screwed-up taut. The chairs are suitably formed to give tapered seats for the rails, and to fit the wedge-form channels in the rails, so as to make a firm union. The outer sides of the rails are flat, and are flush with the body of the chair at both sides, presenting two vertical walls for the paving-sets. The space under the rails, between the chairs, is filled with concrete, and finished with a layer of asphalt, placed between the twin-rails to form the floor of the groove, which is thus finished to a depth of 2½ inches.

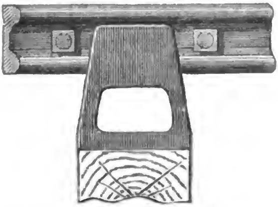


FIG. 54. New double-rail system, by Mr. C. H. Beloe. Scale, $\frac{1}{12}$.

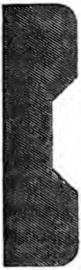


FIG. 55. New double-rail system, by Mr. C. H. Beloe. Section of rail, 30 lbs. per yard. Scale, ½.

An alternative method of construction is shown in fig. 56, in which the channelled sides of the twin-rails are turned outwards. By this arrangement an ordinary bolt and nut may be employed to fasten the rails, as the head and the nut can lie in the channels clear of the paving-sets.

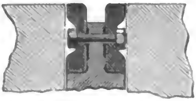


FIG. 56. New double-rail system, by Mr. C. H. Beloe. Scale $\frac{1}{12}$.

Mr. Beloe claims the following amongst other advantages in favour of his new system:—the saving of the cost of longitudinal sleepers, the rail being self-supporting; the distribution of the metal in the rail, as a double-headed rail; the ease with which rails of this section can be rolled; the means of tightening the fastenings of the rails by the double-ended screw, without disturbing the pavement. The rails can be reversed when one head is worn. A light single-headed rail would weigh 21 pounds per yard, or 42 pounds in duplicate; and the heaviest section which it is proposed to employ would weigh 60 pounds per yard, in duplicate. The points and crossings can be forged out of the rails, dispensing with the employment of cast-iron as a material for points and crossings.

A new bolt-fastening has recently been devised by Mr. Beloe, as a substitute for the double-ended screw; it can be more easily removed, in case of fracture.

# CHAPTER VI.

## MANCHESTER CORPORATION TRAMWAYS:—BARKER'S SYSTEM, 1877.

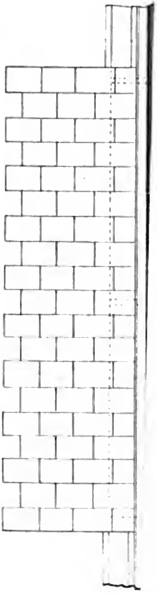
PLATE V.

THE first contract for the Manchester Corporation Tramways, was completed on the 8th of May, 1877, and opened on the 12th of the same month. It consists of three sections, as follows:—

1. Lower King Street, Bridge Street; leading to Salford and Pendleton.
2. Deansgate; terminus in Manchester.
3. Hunts Bank, Bury New Road, to the City boundary; leading to Higher Broughton.

The total length is two miles, comprising half a mile of double way, and 1½ miles of single way, with six passing places. The maximum gradient on the line is at the rate of 1 in 40. After six months of working the single line in Bury New Road, it has been found that it cannot be worked to advantage as a single line; and it has been proposed to lay a second line of tramway in that road, on Barker's system. The application of this system is to be extended to other lines under the control of the Manchester Corporation. The system is adopted

MANCHESTE



Crosby Lockwo

also for the lines of tramway in course of construction at Patricroft; and for lines to Newton Heath, Levenshulme, Openshaw, and other places.

The Manchester lines were constructed under the superintendence of Mr. J. H. Lynde, C.E., on the system of iron way shown in Plate V., patented in March 1876, by Mr. Benjamin Barker. The peculiar features of this system are the longitudinal cast-iron sleepers, which afford a continuous bearing for the rail and for the adjoining paving-sets; and the grooved rail, of which the lower surface is indented longitudinally, and is formed with a central flange or web, by which it is fastened by cotters to the sleeper. The sleeper is, in section, like the ordinary bridge-rail in use on railways; but it is of larger dimensions. It consists of a hollow vertical portion, 3 inches wide, finished with a solid head, formed to fit and to carry the rail; and two horizontal flanges, about 4 or 4½ inches wide, making in all a broad continuous base 12 inches in width. The total height of the combined sleeper and rail is 7⅜ inches, and the clear height above the flange-base is 6⅞ inches, leaving a ⅞-inch space for bedding under the paving-sets, which are 6 inches deep, and adjoin the rail. The sleepers are cast in lengths of 2 feet 11½ inches, and are stiffened by two transverse webs between the vertical ribs. The thickness of metal of the sleeper is ½ inch, except for the flanges, which are made ⅝ inch thick at their roots, next the vertical ribs, and taper in thickness to ⅜ inch at their edges; except also the head of the sleeper, which is sufficiently massed to provide a solid bearing and attachment for the rail, and a vertical wall at each side, as an abutment for the stone sets. The castings were made from re-melted iron, containing at least one-sixth part of scrap. Two test-bars were cast each day that any of the castings were run, 1 inch wide, 2 inches deep, and 3 feet 6 inches long; one of which was tested edgewise on bearings 3 feet apart, and was not to break with any weight less than 27 cwt. applied at the middle. If the test-bar failed to sustain the test, all work cast from the same melting was rejected. Each sleeper, 2 feet $11\frac{1}{2}$ inches in length, was to weigh not less than 137 pounds; being, for a length, reckoned as 3 feet, at the rate of 137 pounds per lineal yard. The position of the holes for the keys, cast in the sleepers, was not to vary more than $\frac{1}{16}$ inch from the given position.

The rails were rolled of Bessemer steel, 3 inches wide, and weighed 40 pounds per yard. They were rolled in lengths of 18, 21, and 24 feet. The tread or rolling surface of the rails is $1\frac{1}{2}$ inches wide, and is rounded with nearly $\frac{1}{8}$ inch of rise; the groove is $1\frac{1}{8}$ inches wide, and $\frac{11}{16}$ inch deep below the summit of the tread; the outer ledge is $\frac{3}{8}$ inch wide at the surface, and is $\frac{1}{8}$ inch lower than the tread. The side of the groove next the tread is vertical, the bottom of the groove is $\frac{3}{4}$ inch wide, and the whole of the taper of the groove is directed towards the ledge. The lower side of the rail is longitudinally indented, and is strongly formed with inclined flanks, from which the central web depends. The web is $\frac{1}{2}$ inch thick, and the total depth of the rail amounts to 3 inches. The indentations of the rail fit on the corresponding wedge-formed surfaces of the head of the sleepers, and the rail is fastened to the sleepers by horizontal cotters of hard wrought-iron, ½ inch by ⅜ inch, slightly taper, which pass right through the flange of the rail, and the head of the sleeper. There is one cotter to each sleeper, except at the joints of the rails, where there is one cotter extra for each end. By this method of attachment, the rail is secured by the indented surfaces against lateral displacement, whilst the chief function of the cotter is to hold it down to the sleeper.

It was required that the rails should be manufactured from a mixture of the best English hematite brands and spiegeleisen, cast into ingots of sufficient weight to make one or more rails. The curved rails were bent, cold, in a bending machine, to the required radii. The flanges of the rails were punched for the cotter-holes; and the holes were required to be within $\frac{1}{16}$ inch of the proper position.

The way is laid to a gauge of 4 feet 8½ inches, with an interspace 4 feet wide between the two lines of a double way. The new pavement is not confined to the customary breadth of 18 inches outside the ways, but is, in some cases, laid for the whole width of the carriage-way to render the whole of the surface uniform. Allowing, for purposes of comparison, the usual 18-inch breadths of paving outside the ways, the total width for a double way is made up thus:—

| | Feet | Inches |
|---|---|---|
| Two widths of gauge, 4 feet 8½ inches | 9 | 5 |
| Interspace | 4 | 0 |
| Two breadths of 18 inches | 3 | 0 |
| Four half-widths of rail (1½ inches × 4) | 0 | 6 |
| | 16 | 11 |

The sleepers are not fastened together, but are placed ½ inch apart between end and end, and make up intervals of 3 feet for each straight sleeper. For sharp curves, the sleepers are laid in shorter segments, 18 inches in length. Sleepers have been cast to match curves in some instances; but, it is said, it is not necessary to provide sleepers of a curved form.

The roadway was excavated to a uniform depth of about 8 inches. The bottom of the excavation was taken as the foundation for the sleepers, as the ground was considered to be sufficiently consolidated to support the tramway with its extensive bearing surface, without the assistance of special concrete foundations. The sleepers were, nevertheless, for the purpose of packing, bedded on a 1-inch layer of rough mortar. Before being laid, they were filled with rough mortar. The mortar was composed of three parts of clinker, and one part of Ardwick (hydraulic) lime, ground in a mill.

The rails were bedded on the sleepers in gas-tar, which aids in filling up any chance vacancies between the sleepers and the rails. The flat rails, without grooves, were only laid, as outer rails, at one curve of the way, having a radius of 32 feet.

The paving is of granite sets, 3 inches wide, and 6 inches deep, laid on a 2-inch bedding of small gravel, or old macadam. The joints were filled with pea-gravel or small granite chips, and grouted with a boiling mixture of pitch and creosote, on the system which has for years been practised in laying pavement in Manchester.[1]

---

[1] For some account of the Manchester system of paving, see *Construction of Roads and Streets*, 1877. Crosby Lockwood & Co.

The contractors are required to replace any sleepers or rails found to be defective for a period of twelve months after the work was completed. Payments were made at intervals to the extent of 80 per cent. of the value of the work executed; the balance was payable at the expiration of three months after the completion of the works.

In one mile, single line, of Mr. Barker's system of tramway, as laid in Manchester, there are 215 tons of cast-iron sleepers, and 63 tons of steel rails. Of the mortar bedding for the sleepers, 40 tons per mile was used. The price of the rails, delivered, was £8. per ton, and that of the sleepers was £5. 4*s.* 6*d.* per ton. The mortar bedding cost 7*s.* 6*d.* per ton, delivered on the ground. The total cost for materials and labour, to remove the old paving, prepare the bed for the sleepers with a layer of rough mortar 1 inch thick, and lay in the tramway complete (exclusive of all charge for paving), was £2,320 per mile, single line. The annexed is a cost-list comprising the items of cost in tabular form:—

MANCHESTER CORPORATION TRAMWAYS, BARKER'S SYSTEM.—
COST PER MILE, SINGLE LINE, 1877.

| | £ | *s.* | *d.* | £ | *s.* | *d.* |
|---|---|---|---|---|---|---|
| 215 tons cast-iron sleepers | @ 5 | 4 | 6 | 1,123 | 7 | 6 |
| 63 tons steel rails, 40 lbs. per yard | @ 8 | 0 | 0 | 504 | 0 | 0 |
| 1,760 lineal yards, labour, mortar-bed, and royalty | @ 0 | 7 | 3 | 638 | 0 | 0 |
| Wedge keys | | | | 25 | 0 | 0 |
| Carting materials (iron only) | | | | 29 | 12 | 6 |
| Cost of way | | | | 2,320 | 0 | 0 |
| 4,400 square yards of paving | @ 0 | 12 | 0 | 2,640 | 0 | 0 |
| Total | | | | £4,960 | 0 | 0 |

A rail and chair, fig. 57, of the same principle of construction, and of lighter scantlings than those employed for the tramways in Manchester, have been designed for country lines of light traffic, paved with 4-inch sets, or for foreign lines laid with macadam. The rail, of steel, weighs 31½ pounds per yard; it is 2¾ inches wide, and has a rolling surface 1½ inches wide. The sleeper weighs 90 pounds per yard; the base of the sleeper is 10 inches wide, and it is 5 inches below the level of the rail. The tie-rods, to be used for macadam roads, are of bar-iron, ⅞ inch by ¼ inch, fastened by cotters driven through at the outer sides of the sleepers. The cost of this pattern of construction amounts to £1,650 per mile, exclusive of paving.

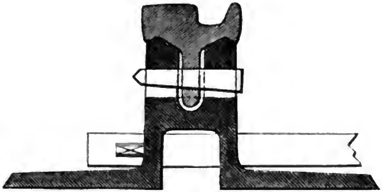
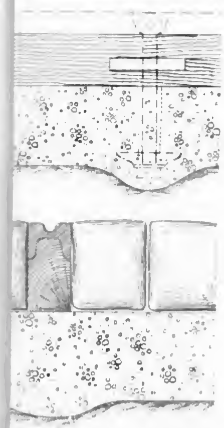
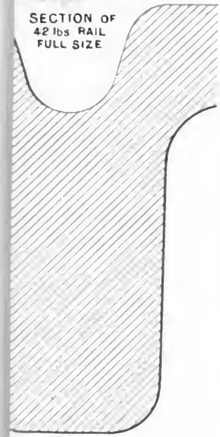


FIG. 57. Barker's system, designed for country lines of light traffic. Rail, 31½lbs. per yard. Scale, ¼.

**LIVERPOOL TRAM**




SECTION OF 42 lbs RAIL FULL SIZE

Lockwood and Cº 7 Statione

# CHAPTER VII.

## LIVERPOOL TRAMWAYS :—DEACON'S SYSTEM, 1877.

PLATE VI.

THE Liverpool Tramways are (December 1877) being reconstructed on the system of Mr. George F. Deacon, the borough engineer, and under his superintendence.

### INNER CIRCLE.

The plans and specifications for the reconstruction of the 'inner circle,' by which all the outer lines are connected, were prepared by the borough engineer, and approved by the engineer to the Liverpool Tramways Company. The leading feature of Mr. Deacon's system, illustrated by Plate VI., is the method of fastening the rail to the longitudinal sleeper and the foundation of concrete, by means of a central bolt. The fastening is suitable for a side-groove or a central-groove rail; but in Liverpool the central groove has been adopted. The width of exposed metallic surface is thereby reduced to a minimum, whilst the whole area not occupied by the groove being utilised as tread, the total width of tread or rolling surface is greater than that of the ordinary grooved rail.

In order at once to place the pavement and the rails on the same foundation, and to render the whole surface uniform, the streets of the inner circle have been entirely repaved, and provided with new foundations of concrete for their whole width of carriage-way, simultaneously with the laying of the tramways. The old foundations of the tramways and of the streets have been entirely taken out, and the excavation cleared to a depth of 14¼ inches below the permanent surface of the street. On the bottom, a foundation of concrete, made with Portland cement, 7 inches deep, is laid for the whole width of the street, and finished with a perfectly smooth surface. The concrete is left alone to set and harden, for eight days at least, before any paving is laid. The longitudinal sleepers on which the rails are laid, are of Memel, Dantzic, or Riga red-pine, 5⅜ inches deep and 3¼ inches wide. For straight lengths, they are of either of two lengths—24 feet 2 inches, or 18 feet 1½ inches. For curves, they are in lengths of 6 feet ⅜ inch, sawn from the solid wood to the required curvature. The upper surface of the sleeper is moulded to the form of the rail. Openings are cut into the sleeper, from the upper face and one of the sides, to receive the fastenings. All the sleepers are creosoted with not less than 10 pounds of creosote oil per cubic foot of timber. The sleepers are placed in position when the concrete becomes perfectly firm, and after the nuts have been placed on the holding-down bolts.

The rails are of Bessemer steel, weighing 61 pounds per yard, rolled in lengths of 24 feet 2 inches, with ten per cent. 21 feet or 17 feet in length, and making-up pieces of shorter lengths. They are

3¼ inches wide, and 3¼ inches deep over the flanges. The groove is in the middle of the upper surface, 1 inch wide and 11/16 inch deep, formed to a semicircle at the bottom. The upper bearing surfaces at the sides of the groove are each 1⅛ inches wide—together 2¼ inches. Some allowance, Mr. Deacon admits, must be made for defective gauging of wheels and rails; but he is of opinion that even ¾ inch is ample width of groove. The thickness of the rail, measured from the surface, is 1⅜ inches. Under the groove, the thickness is reduced to a half, or 11/16 inch; but, as the depth of the groove is twice as great as the depth of the wheel-flanges, the rail cannot be worn at this point. The flanges depend 1⅞ inches below the head; they are of great strength, being ½ inch thick near the edges, and thickening upwards. The test applied to the rails is the fall of a weight of 20 cwt., through a height of 12 feet, upon the middle of a rail laid on supports, at a span of 5 feet. If the rail be cracked under this test, the other rails made from the same charge are liable to be rejected. The rails are also tested by chemical analysis. Such as are found to contain less than 0·30, or more than 0·45, per cent. of carbon, are liable to be rejected.

The rails are coated at the under side with thick coal-tar, preparatory to being laid in position on the sleepers. They are fastened by means of a central ¾-inch bolt of adjustable length, formed with an eye at the upper end, which embraces a ¾-inch round iron cross pin, passed horizontally through ⅞-inch round holes in the flanges of the rail. The bolt passes down through the sleeper, and nearly through the stratum of concrete, and is formed with a head at the lower end, which takes a bearing upon a round cast-iron plate or washer, 6 inches in diameter, which, with the lower portion of the bolt, is imbedded in the concrete. The bolt is parted above the concrete, within the body of sleeper, and the parted ends are united by a right-and-left-handed double nut, affording the means of solidly screwing down the rail upon the sleeper, at the openings in the side of the sleeper, and both together to the foundation. When the screwing down is completed, the side opening is covered by a sheet of canvas, coated with red lead. A holding-down bolt is applied at a distance of 8 inches from each end of every rail, and intermediately at intervals of about 3 feet 2 inches. The holding-down bolts are placed in position before the washers are bedded, and each bolt is enveloped in a cast-iron thimble, which is withdrawn after the concrete has set. In laying the washers, a framed template is used, from which the bolts are hung in their proper positions. The wrought iron was to be capable of bearing a tensile stress of 21 tons per square inch. The cast iron was to be of such strength that a bar 1 inch square, 3 feet 6 inches long, should not break with a weight less than 850 pounds applied at the middle, on a span of 3 feet.

The paving-sets are from 7 to 7¼ inches deep, laid on a ½-inch bed of sand; except the sets next the rails, which consist of the most durable stone—the hardest granite, or coarse-grained trap. These are carefully hammer-dressed in such a manner that their edges touch the sides of the rails, and that they touch each other at their surfaces near the rails; so that the upper surfaces of the paving-sets next the rails are practically continuous. Mr. Deacon considers that, by this means, the rate of wear and loss of level of the pavement next the rails, shall be reduced to a minimum, and that the inconvenience of hollows or differences of level between the rails and the pavement shall be obviated. The sets next the rails are bedded on cement instead of sand; they are alternately wholes and halves, and, as they are accurately gauged in all directions, they can be drawn and replaced by similar sets without disturbing the surrounding pavement. The sets are from 5 to 7 inches long, and are of such thickness that four sets, chosen at random, and placed side by side, may measure not more than 14 inches across all the stones. The sets are laid as closely as is consistent with the straightness of the courses. The joints are then filled with clean dry gravel, from $\frac{3}{16}$ inch to $\frac{5}{8}$ inch in diameter, which is shaken down by the ramming of the sets. This process is repeated until the joints are filled with gravel, and the sets no longer shake under the rammer. The joints are finally run up with a boiling mixture of pitch and creosote, by which the smallest crevice or interstice is completely occupied, and the joint is made perfectly watertight.

A short piece of tramway constructed on this plan was laid, in the middle of the year 1875, in substitution for a portion of one of the old lines in Liverpool. The ordinary cars have, since that time, been running upon the new piece in a satisfactory manner.

During the past summer, the whole length of the inner circle has been reconstructed and opened for traffic. The ordinary cars run upon the new line with greater ease, it is reported, than upon the original portions of the line. As the ordinary car-wheels wear out, they are replaced by central-flange wheels, having a tread on each side of the flange. Until the whole of the existing lines are reconstructed, the central-flange wheels will run upon both the side-grooved and the central-grooved rails.

### BRANCH LINES.

The general principle adopted in the construction of the inner circle of tramways, by which uniformity of foundation and of pavement is insured, and by which the rail is firmly secured to the foundation, is maintained in the modified design, Plate VI., proposed for the branch lines, which are thus described:—

Throughout the inner circle, paving-sets from 7 to 7¼ inches deep, have been employed; but these dimensions exceed by one inch the depth of paving-sets generally adopted in Liverpool, for all streets except those of the very heaviest traffic. If rails of the same section as that of the rails laid in the inner circle, were employed for the shallower paving, it would be difficult to reduce the depth of the sleepers by one inch, without unduly cutting away the sleeper at each bolt. For this reason, and also with a view to the arrangement of the fastenings so that the rail may either be fastened down or removed without disturbing any sets, the cast-iron washers differ from those of the Inner Circle, in having a larger hollow to receive the head of the bolt, and having the bolt-hole half an inch larger than the bolt. Before the concrete is laid, the level of the washer is fixed by a slate, placed beneath it, as shown, or by a stone, or a brick, by which the washer is supported. While the concrete is being formed above the washer, the thimble remains round the bolt, and is withdrawn when the concrete has set. The vertical holes through the sleepers, also, are half an inch larger than the bolts. The upper end of the bolt is screwed into a covered nut of phosphor-bronze, which is sunk into the rail through the bottom of the groove, and made a tight fit therein with red-lead. The bolt, where it passes through the rail, is also a good fit. As the bolt is free to move in the concrete, vertically or laterally, with the rail, the joint is free from liability to dislocation by vibration or by weight of traffic.

In the fastenings shown in Plate VI., the cast-iron washer projects upwards, so that its upper side is flush with the concrete. The concrete can therefore be finished off without interference from any such projecting parts. The concrete between the jaws is afterwards scraped out, and the head of the bolt is inserted. When the sleeper is laid, a mixture of boiling pitch and creosote oil is run into the groove to fill the hole in the sleeper and the space between the jaws. This asphalt is plastic when set; and, whilst it prevents the bolt from turning, it allows it to vibrate with the rail. The washer is rectangular in section, 3 inches long by 6 inches crosswise of the rail. With such a fastening, it is said that the tramway can be laid with facility, and as there is a liberty of 3 inches one way, and ¾ inch another way, for setting the bolt-head between the jaws, no special degree of nicety is required in setting the bolt. The fastenings are now in use under the heaviest traffic of Liverpool.

The rail is of steel, and weighs 42 pounds per yard. It is made of a **T** section, having the central groove and a central web. It is 3 inches wide, and 2⅞ inches deep. The nut is screwed up by means of a four-pronged key, and Mr. Deacon's experiments show that one man can readily draw down the rails with a pressure of from 2 to 3 tons at each fastening. The depth of the rail and sleeper together amounts to 6 inches, which is also the depth of the paving-sets. For country or suburban lines, a perfectly firm tramway may be constructed on this principle, by merely laying each line of sleepers on a foundation of concrete, 9 inches or 18 inches wide. In Canada, where timber is plentiful, a line of tramway has been proposed, on the principle of the line now described, without any foundation of concrete, but with longitudinal foundations, consisting of timber sleepers laid flat on their sides, to support the grooved sleepers and the rails.

The employment of cast-iron sleepers, as arranged by Mr. Deacon, is also shown in Plate VI. He does not consider it necessary to sink such sleepers in the concrete. By keeping them above the concrete the laying of the concrete is not interfered with by them. They are bedded on a thin layer of cement.

It has been found in the experience that has been had hitherto of Mr. Deacon's systems of fastening, that neither cross sleepers nor cross ties are necessary. Under the heavy traffic of the principal streets of Liverpool, the gauge has been maintained.

Although Mr. Deacon recommends the application of the central groove for tramways which are not to be connected to side-groove lines, yet the principle of the rails and fastenings which he has adopted may with equal facility be employed for side-groove rails, as shown in Plate VI.

The annexed table contains particulars of the cost of construction of tramways on Mr. Deacon's systems, for four kinds of way, illustrated in Plate VI. The third and fourth are two lighter and less costly forms, on the same leading principle of construction as the second design. The rails weigh only 35 pounds per yard, and are of a section absolutely stronger than many rails of older forms and greater weight.

The cost of the stone pavements of Liverpool—exclusive of concrete foundation, comprising the stone-sets, a bedding of sand, and grouting of gravel and asphalt—is about 9*s.* per square yard, when the sets are 6 inches deep, and 6*s.* 6*d.* when the sets are 4 inches deep. The costs per yard forward, and per mile, comprising two 18-inch breadths outside the rails, are as follows:—

| SINGLE LINE | Per yard forward £ | *s.* | *d.* | Per mile £ |
|---|---|---|---|---|
| For sets 6 inches deep . . | 1 | 2 | 6 | 1,804 |
| Do. 4 do. . . | 0 | 16 | 3 | 1,430 |

## CROSSINGS AND POINTS.

Throughout the reconstructed lines, the crossings are formed by bevelling the ends of one of the lines of rails, and cutting a groove across the other line of

## LIVERPOOL TRAMWAYS:—DEACON'S TRAM

### *Quantities and Approximate Cost per Yard*

| Description of material or work | No 1. Plate VI.<br>Tramway as relaid in Inner Circle, Liverpool. Foundation of concrete, 8 feet wide.<br>Rail, 61 lbs. per yard | | | | | | |
|---|---|---|---|---|---|---|---|
| | cwt. | qr. | lbs. | oz. | £ | s. | d. |
| Bessemer steel rails | 1 | 0 | 10 | 0 | 0 | 8 | 8 |
| Wrought-iron screwed bolts, nuts, and pins | 0 | 0 | 6 | 8 | 0 | 1 | 5 |
| Two cast-iron washers | 0 | 0 | 10 | 8 | 0 | 0 | 8 |
| Two solid-ended phosphor-bronze nuts (screwed) | None | | | | 0 | 0 | 0 |
| Holes drilled in rails | 2 holes | | | | 0 | 0 | 4 |
| Baltic red-pine sleepers, seasoned, shaped, and creosoted; two lineal yards | 6″ × 3¼″ = ·81 cu. ft. | | | | 0 | 2 | 10 |
| Drilling and cutting holes for fastening in sleepers | — | | | | 0 | 0 | 8 |
| Foundation | P. cement concrete, 7½″ deep, 2⅔ sq. yds. | | | | 0 | 11 | 0 |
| Excavation | — | | | | 0 | 3 | 4 |
| Labour in laying rails and sleepers | — | | | | 0 | 2 | 0 |
| | | | | | £ | s. | d. |
| Cost per lineal yard (exclusive of paving) | — | | | | 1 | 10 | 11 |
| Cost per mile ( do. do. ) | — | | | | 2,721 | 0 | 0 |

NOTE TO TABLE.—The cost for paving, in sets 6 inches deep, comprising the 18-inch

WAYS, WITH COMPENSATING FASTENING.

*Forward, Single Line (Exclusive of Paving).*

| No. 2. Plate VI.<br>Tramway proposed for urban branch lines, Liverpool. Foundation of concrete, 8 feet wide.<br>Rail, 43 lbs. per yard | | No. 3.<br>Same as No. 2, with foundation of concrete, 12 inches wide under each sleeper.<br>Rail 35 lbs. per yard | | No. 4.<br>Same as No. 3, with cross timber sleepers at average intervals of 3½ feet, instead of concrete.<br>Rail, 35 lbs. per yard | |
|---|---|---|---|---|---|
| qr. lbs. oz. | £ s. d. | qr. lbs. oz. | £ s. d. | qr. lbs. oz. | £ s. d. |
| 3 2 0 | 0 6 2 | 2 14 0 | 0 4 10 | 2 14 0 | 0 4 10 |
| 0 2 10<br>(No nut or pin) | 0 0 7 | 0 2 10<br>(No nut or pin) | 0 0 7 | 0 1 15¼ | 0 0 6 |
| 0 14 0 | 0 0 10 | 0 14 0 | 0 0 10 | 0 5 7⅔ | 0 0 4 |
| 0 0 6½ | 0 1 0 | 0 0 5 | 0 0 9 | 0 0 5 | 0 0 9 |
| 4 holes | 0 1 0 | 4 holes | 0 1 0 | 4 holes | 0 1 0 |
| 5½" × 3" = ·688 cu. ft. | 0 2 8 | 5½" × 3" = ·688 cu. ft. | 0 2 8 | 5½" × 3" = ·688 cu. ft. | 0 2 8 |
| — | 0 0 3 | — | 0 0 3 | — | 0 0 3 |
| P. cement concrete, 5" deep, 2⅔ sq. yds. | 0 7 6 | P. cement concrete, 6" deep, ⅔ sq. yds. | 0 2 3 | 2 lin. yds. cross sleepers | 0 2 7 |
| — | 0 2 6 | — | 0 2 0 | — | 0 2 0 |
| — | 0 1 1 | — | 0 1 1 | — | 0 1 3 |
| — | £ s. d.<br>1 3 7 | — | £ s. d.<br>0 16 3 | — | £ s. d.<br>0 16 2 |
| — | 2,076 0 0 | — | 1,430 0 0 | — | 1,423 0 0 |

breadths outside the rails, is £1. 2*s.* 6*d.* per yard forward, or £1,804 per mile.

rail. The fixed points are of chilled cast iron, and those which are movable have shear-steel tongues. In the ordinary side-grooved point, the tread of the wheel travels for some distance only on the thin edge of the point, and so rapidly wears it down. When the point is thus worn, the wheel sinks and runs below the level of the rail; and, in passing over the point, from the branch to the main line, it has to remount on the main line rail, an operation by which an inclined plane is gradually worn into the surface of the rail. This evil, it is thought, is to a great extent obviated by the use of the central-flanged wheels employed to run upon Mr. Deacon's rails; for, one of the treads of the wheel has always a bearing upon the tread of the rail. In order still further to increase the width of bearing surface, the width of the groove at and near the point is reduced as much as is practicable; and the wheel, in running over the point from the branch line, arrives in a much shorter distance upon the tread of the main-line rail. With the same object in view—the preservation of continuity of bearing surface—the depth of the groove at and near the joint is made the same as the projection of the wheel-flange.

# CHAPTER VIII.

## MR. ROBINSON SOUTTAR'S SYSTEM OF TRAMWAY.

MR. ROBINSON SOUTTAR designed a system of tramway, with a timber substructure, patented by him in March 1876, and illustrated in figs. 58 to 61. It is a system of transverse and longitudinal sleepers, upon which double-flanged grooved rails are carried. The following description is abstracted from a complete specification.

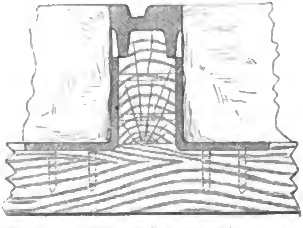


FIG. 58. Mr. Robinson Souttar's system of tramway. Scale, $\frac{1}{8}$.

For a gauge of 4 feet 8$\frac{1}{2}$ inches, the roadway is to be excavated for a width of about 8 feet for a single way, and 16$\frac{1}{2}$ feet for a double way; with a flat floor, to a depth varying with the quality of the ground, averaging about 14½ inches, and never less than 12½ inches. A foundation of concrete, 7 inches deep, is to be prepared and laid in the following manner. The concrete is to be composed of—

| | Measures |
|---|---|
| Portland cement | 1 |
| Clean, sharp, sandy gravel | 4 |
| Broken stone | 5 |
| | 10 |

The cement is to be of the very best quality, weighing 87¼ pounds per cubic foot, without having been pressed; it is to pass through a sieve of 50 meshes to the inch, excepting, it may be, a quantity not more than 10 per cent. rejected by the sieve. The cement when tested for tensile strength is not to break with a load of less than 800 pounds on a section of 2¼ square inches area, after having been immersed in water for 7 days. The gravel is to be free from dirt, clay, loam, or other impurity. To mix the cement, the gravel is to be spread on boards—not on the ground—in quantities of not more than 5 cubic feet at a time. The cement is to be spread uniformly over the gravel, and thoroughly mixed with it in the dry state; then water is to be added, from a small tank, distributed through a rose, and the whole is to be thoroughly mixed in the wet state. The concrete is to be protected

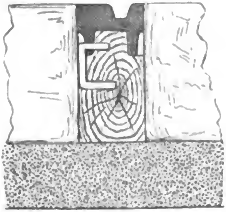


FIG. 59. Mr. Robinson Souttar's system of tramway. Scale, ⅛.

whilst setting from the influence of excessive sunshine, heavy rain, or frost.

A bed of fine concrete, 3 inches deep, is to be laid on the ground for each cross sleeper, into which the sleeper is to be beaten down and adjusted by means of the straight-edge and the level. When the cross sleepers have thus been adjusted, a layer of broken stone, well watered, is to be scattered over the floor of the excavation; upon this a layer of concrete is thrown down, then a second layer of

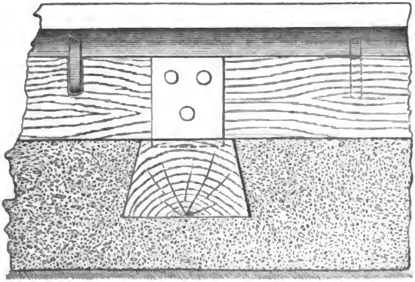


FIG. 60. Mr. Robinson Souttar's system of tramway. Scale, $\frac{1}{8}$.

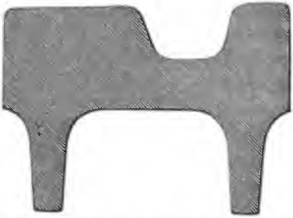


**FIG. 61. Mr. Robinson Souttar's system of tramway. Section of rail, 55 lbs. per yard. Scale, $\frac{1}{2}$.**

broken stone is to be laid on and beaten into the concrete. These are to be succeeded by alternate layers of concrete and broken stone, until the surface level of the cross sleepers is reached, when the mass is to be finished with a layer of fine concrete well beaten and flushed uniform with the surface of the cross sleepers, making a total depth of 7 inches of concrete. The proportion of broken stone and gravel to cement in this mixture is not to average more than 9 to 1.

The sleepers are to be of the best Baltic red pine, sawn on all sides true and square, and creosoted with 10 pounds of creosote oil per cubic foot. The cross sleepers are to be 7 feet 6 inches long, of a trapezoidal section, 4 inches deep, 7 inches wide at the lower side, and 5 inches wide at the upper side. They are to be laid at a distance apart of 6 feet between centres, except at points and crossings, where additional sleepers may be required. The longitudinal sleepers are to be 4 inches wide, and 6 inches deep; the straight sleepers are to be cut into lengths of 18 feet, 24 feet, and 30 feet. Curvilineal sleepers are to be accurately sawn from solid wood, and for curves of less radius than 300 feet the lengths may be reduced to 12 feet. The longitudinal sleepers are to be square-jointed and accurately rebated to fit the rail; they are to be fastened by wrought-iron brackets, one at each side, to the cross sleepers:—of ¼-inch plate, 4 inches wide, let flush into both sleepers, and fixed to each with four 3-inch iron spikes.

The rails are to be of Bessemer steel, weighing 55 pounds per yard; to be in lengths of 24 feet, with a proportionate quantity, not exceeding 5 per cent. of the whole, in shorter lengths, not less than 18 feet.

The curved rails are to be bent at the manufactory. The rail, 4 inches wide, is formed with two side flanges, which are not, as in ordinary flanged rails, flush laterally with the head; but they are set inwards, or indented, to the extent of ⅜ inch at each side. The object of the indentation is to admit of the staples employed to fasten the rail, being driven flush with the sides of the sleeper and the rail, so that there may not be any projection which would prevent the paving-sets from abutting closely against the rail; to avoid the formation of grooves and ruts in the pavement. Each 24-feet rail is to be punched for 18 holes alternately through the sides of the rail; shorter lengths in proportion. The ends of the rails are to be stayed by joint-plates 12 inches long, 2 inches wide, and ½ inch thick, let flush into the sleepers, and fitted to the rails. The staples or side-fastenings are each to be fashioned out of one piece of Lowmoor iron, ¾ inch wide and ⅜ inch thick. The upper end is to be round and chisel-pointed; the lower end is to be pointed and jagged. A recess is to be gouged out of the side of the sleeper to receive the body of the staple, and take it in flush. The longitudinal sleepers are to be pressed into the rails by means of powerful hand-screw cramps, and they are to be so held together until the staples are driven.

The rails are to be laid so that the joints of the longitudinal sleepers shall be as nearly as is practicable equally distant from those of the rails: in every case, at least 4 feet from the joints of the rails. The bent rails are to be in all cases adjusted by means of a cramp, and not by swaging or by hammer-blows.

In the following estimate of the cost per mile, single line, of a street tramway on Mr. Souttar's system, a uniform bed of cement-concrete, 7 inches thick, for the whole width, is included. The cost of paving is not included:—

Estimated Cost of an Urban Tramway on Mr. Robinson Souttar's System, per mile, single line.

| Work and materials | Quantity | Rate | Amount | | |
|---|---|---|---|---|---|
| | | | £ | *s.* | *d.* |
| Excavation, and removing surplus | 4,693 sq. yds. | 9*d.* | 175 | 19 | 9 |
| Concrete in Portland cement, 7 inches deep | 4,693 sq. yds. | 3*s.* 6*d.* | 821 | 5 | 6 |
| Longitudinal sleepers, creosoted | 10,560 feet | 6¼*d.* | 275 | 0 | 0 |
| Cross sleepers, creosoted | 880 | 4*s.* | 176 | 0 | 0 |
| Steel rails, 55 lbs. per yard | 86 tons | £8 | 688 | 0 | 0 |
| Fastenings, 7,040 per mile | 2,816 lbs. | £21 (per ton) | 26 | 8 | 0 |
| Joint-plates | 440 | 6*d.* | 11 | 0 | 0 |
| Brackets, 3,520 per mile, @ 2½ lbs. | 8,800 lbs. | £12 (per ton) | 47 | 2 | 10 |
| Three-inch spikes | 1,120 lbs. | £27 | 13 | 10 | 0 |
| Laying, watching, and lighting | 1,760 yards | 2*s.* | 176 | 0 | 0 |
| Total cost (paving extra) | £1. 7*s.* 4½*d.* per yard. | — | 2,410 | 6 | 1 |

'A uniform and thick bed of Portland cement-concrete has been estimated for; and this would be desirable in a street subjected to heavy traffic. In the suburbs, and wherever economy is the first consideration, this item could be greatly reduced, and under similar circumstances a lighter rail might suffice.'

# CHAPTER IX.

## HARBOUR TRAMWAYS.

### GLASGOW HARBOUR TRAMWAY.

TRAMWAYS suitable for goods-yard traffic, consisting of two cast-iron tram-plates and iron paving between them, have been down in the Devonshire Street Station of the Great Eastern Railway, London, for upwards of 20 years.

A cast-iron tramway, bedded in concrete, chiefly designed for street or dock lorrie-traffic, was patented in December 1869, by Messrs. Ransome, Deas, & Rapier. A tramway on this system, 4½ miles long, was laid, in 1870, on the Broomielaw Quay, at Glasgow. It is adapted for both flanged and unflanged vehicles. The way consists of hollow rectangular blocks of

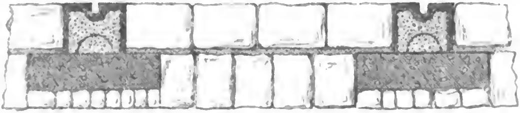


FIG. 62. Glasgow Harbour Tramway:—System of Messrs. Ransome, Deas, & Rapier. Scale, $\frac{1}{24}$.

cast iron, figs. 62 and 63, 5 feet long, 10 inches wide, and 8¼ inches deep; 1 inch thick at the top, and ½ inch at the sides. A groove, 1½ inches wide, and 1½ inches deep, is formed in the middle of the upper surface of the block, for wheel-flanges. The upper surface, cast on a chill, is formed with grooves at each side, to afford a foothold for horses. Recesses at the ends are cast to receive fish-plates, which are bolted in the ordinary manner. The blocks were entirely filled with concrete, composed of 7 parts of gravel and sand, and 1 part of Portland cement, well punned, and allowed to lie three or four days to set. The bottom was prepared like that of an ordinary first-class street or dock-road, consisting of dry rubble, and two lines of concrete were prepared for the tram-blocks, 1 foot 10 inches wide, and 6 inches deep. The tramway blocks were then turned over, and were fixed with cement to the bases of concrete.

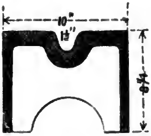


FIG. 63. System of Messrs. Ransome, Deas, & Rapier. Section of rail, 203 lbs. per yard. Scale, $\frac{1}{12}$.

At first, it seemed desirable to have bottom flanges at the outsides of the blocks, but it was found inconvenient for laying the paving-sets. Bottom flanges were then applied at the insides; they answered well, but for the sake of economy of material, flanges were entirely dispensed with, and the tramway blocks constructed as shown in the illustration have been found to be perfectly steady. The road was made thoroughly rigid; and the blocks, once laid, remained there. At first, cross tie-bars were used, but it was found that they were not necessary, for the blocks could not be got to stir even when it was required to move them. In a few instances, where it was necessary to have the blocks raised for laying water-pipes or gas-pipes, it was found that they had stuck to the concrete beneath, and had to be actually cut away.

The quantities and costs for this system of tramway are as follows, for a single way:—

SINGLE WAY.

Cast-iron blocks, 406 lbs. per lineal yard of 2 rails; or 319 tons per mile.

Concrete, 0·30 cubic yard per lineal yard; or 528 cubic yards per mile.

| | Per lineal yard | | | | Per mile | | |
|---|---|---|---|---|---|---|---|
| | £ | s. | d. | | £ | s. | d. |
| Cost of cast-iron blocks, including fish-plates, and bolts and nuts . . | 1 | 5 | 0 | ... | 2,200 | 0 | 0 |
| Cost of concrete, @ 15*s.* 6*d.* per cubic yard . . | 0 | 4 | 8 | ... | 410 | 13 | 0 |
| Laying . . . . . | 0 | 2 | 6 | ... | 220 | 0 | 0 |
| | £1 | 12 | 2 | ... | £2,830 | 13 | 0 |

To this there is to be added the cost for excavation and for pavement.

The experience of this tramway at Glasgow has been very satisfactory. From 100 to 140 railway waggons pass over the busiest part of the tramway daily. Contractors' locomotives also constantly pass, frequently dragging heavy loads upon bogies to the 60-ton crane. The highest speed of the railway vehicles is about 5 miles per hour, and of the street lorries 6 miles per hour. It is notable that, when horses have to turn off the tramway, they return to it of their own accord. From the report of Mr. Deas, who is engineer to the Clyde Navigation, it appears that none of the cast-iron blocks have been broken, and that the chilled surfaces are now in as good condition as when the way was first laid. It was originally expected that, in order to get the blocks to lie steady, they would require to be cast in 10-feet lengths; but it was found not to be necessary, for the 5-feet blocks never showed any signs of movement.

A variety of the same kind of tramways is shown on fig. 64, for flanged vehicles only. The cast-iron block is only 4 inches wide at the surface, and it is formed with side flanges at the bottom, making up the base to a width of 9 inches. The edges are notched at intervals of 3 or 4 inches for the use of vehicles crossing the road. The blocks are filled with concrete, and laid with cement on two lines of concrete, 6 inches deep and 18 inches wide. The quantities and costs for a single way are as follows:—

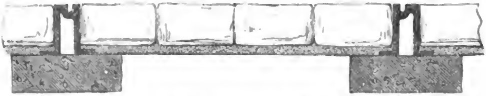


FIG. 64. System of Messrs. Ransome, Deas, & Rapier, for lighter traffic. Scale, $\frac{1}{24}$.

Cast-iron blocks, 308 lbs. per lineal yard of two rails; or 242 tons per mile.

Concrete, $\frac{1}{5}$ cubic yard per lineal yard; or 352 cubic yards per mile.

| | Per lineal yard | | | Per mile |
|---|---|---|---|---|
| | £ | *s.* | *d.* | £ |
| Cost of cast-iron blocks, including fish-plates, bolts, and nuts | 0 | 19 | 0 | 1,672 |
| Cost of concrete, @ 16*s.* 3*d.* per cubic yard | 0 | 3 | 3 | 286 |
| Laying | 0 | 2 | 3 | 198 |
| | £1 | 4 | 6 | £2,156 |

In 1871, a length of about 700 yards of tramway on this system was laid in the gas-yard of the Glasgow Corporation. The manager has reported that it worked very well, had not required any repair, and had not occasioned any trouble.

---

### Belfast Harbour Tramway.

A single line of tramway, specially designed for the traffic, was laid, in 1869, on the quays at Belfast Harbour, under the superintendence of Mr. Lizars, the engineer to the Harbour Commissioners. It was opened in January 1870. It is a single line, with sidings. It consisted of two longitudinal sleepers of pitch-pine, or of Memel timber, 9½ inches wide and 7 inches deep, fig. 65, upon which an ordinary iron bridge-rail, 4 inches deep, weighing 80 pounds per yard, was laid, and fastened by spikes through the flanges. A check-rail of L section, also 4 inches deep, weighing 39 pounds per yard, was laid and

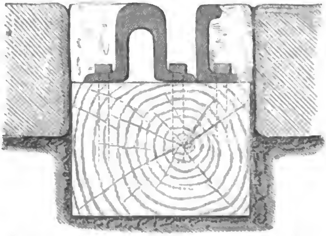


Fig. 65. Belfast Harbour Tramway:—Lizar's System. Scale, $\frac{1}{8}$.

spiked alongside the bearing rail, upon the same sleeper, leaving an interval or groove of a width of 1⅝ inches. The ground was excavated with trenches for the sleepers, which were bedded upon gravel or on ashes. The pavement consisted of oblong sets, 7 inches deep, on a bed of sand, grouted with lime, abutting on the sleepers.

It is apparent that, on this system, wide vacancies were created between the rails and the pavement, 2¼ inches at each side; these vacancies were filled with concrete flush with the pavement. But there was a want of stability in the combination. It was extremely liable to get out of order; the check-rail, no matter how tightly spiked to the sleeper, being easily pressed and moved inwards against the non-resistant concrete; and the groove was thus widened to an extent which was dangerous for traffic.

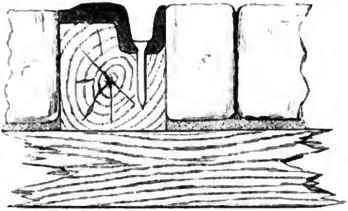


FIG. 66. Belfast Harbour Tramway:—Salmond's System. Rail, 70 lbs. per yard. Scale, ⅛.

A better system was subsequently designed and employed by Mr. T. R. Salmond, the present engineer to the Commissioners, for extensions and for replacements of portions of the line. A single iron rail, fig. 66, of a massive section, weighing 70 pounds per yard, was substituted for the combined bridge-rail and check-rail. It is 6 inches wide, formed with a groove 1½ inches wide, and 1¾ inches deep, and a raised bearing surface at one side of the groove. The average thickness is about ¾ inch. It is fastened by ⅝-inch vertical spikes, ragged, with countersunk heads, to a longitudinal sleeper, 6 inches square, at intervals of 3 feet, except at the joints, where it is fastened by ⅝-inch bolts and nuts. The nuts, at the under side, are screwed-up on a fish-plate of iron of the width of the sleeper, 12 inches in length, and ½ inch thick. The longitudinal sleepers are laid on and spiked to cross sleepers of larch, 9 feet in length, laid at distances of 4 feet between centres.

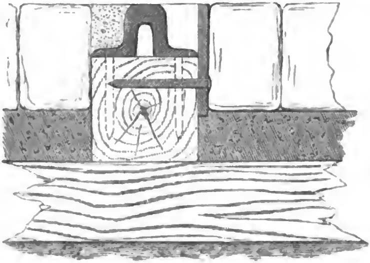


FIG. 67. Belfast Harbour Tramway:—System adopted for sharp curves. Scale, ⅛.

The pavement consists of sets, 6 inches deep, 3½ to 4 inches wide, and from 8 to 12 inches long, laid close to the sleeper and rail at each side.

In the construction of sharp curves, the combination, fig. 67, is applied, consisting of a bridge-rail, laid on a longitudinal sleeper, 6 inches square, and a flat plate, ¾ inch thick, 6½ inches deep, spiked to one side of the sleeper, forming a 1¾-inch groove. The rail of the section here shown lends itself to the formation of curves more readily than the solid wide rail used for the straight portions of the line. It may be noted, too, that the lateral slab which is placed as a check-rail, may be more firmly fixed to the sleeper than the check-rail used in the earlier design.

The new rails were ordered in 1873, with a flat surface, and were partially used for constructing 100 yards of way, in 1875, of which 50 yards was laid in replacement of a portion of the old line. The remainder was used for traversing steam-cranes along the quays. In 1875, new rails were ordered, having a raised surface; they were laid on the new Queen's Quay. The new lines give great satisfaction; it is reported that they lie solidly, and the fastenings keep tight, under the traffic of the railway waggons and locomotives by which they are traversed. The permanency of the fastenings, it is clear, is due to the disposition by which they are placed entirely out of the range of the wheels.

The prices paid for the material of the new way were as follows :—

| | £ | s. | d. | |
|---|---|---|---|---|
| Rails, 70 lbs. per yard, delivered . | 7 | 10 | 0 | per ton |
| Longitudinal sleepers, 6 inches square, cut from log, including the labour of laying . . . . | 0 | 3 | 0 | per cubic foot |
| Larch cross sleepers, 9 feet long . | 0 | 3 | 0 | each |
| Square setting . . . . . | 0 | 8 | 0 | per square yard |
| Switches and crossings . . | 13 | 0 | 0 | per set |

# CHAPTER X.

## SUPPLEMENTARY—ON FOREIGN TRAMWAYS.

### PARIS.

When M. Loûbat returned to Paris from America, he introduced his system, slightly modified, figs. 68 and 69, and, in 1853, laid a line of tramway in Paris, from the Place de la Concorde to Passy, in the Avenue de la Reine. This was the first horse-tramway laid in France. It was laid to a gauge of 1·54 metres, or 5 feet ½ inch. The rail was of a semi-hexagonal section at the lower side, to rest upon a wood sleeper, which was chamfered to receive it, and upon which it was spiked diagonally through the sides. A fish-plate of

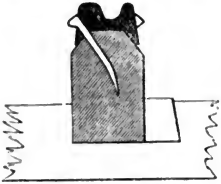


Fig. 68. Loûbat's tramway:—Section of rail and sleeper. Scale, ⅛.

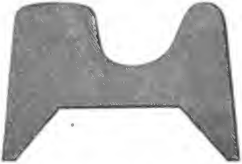


Fig. 69. Section of Loûbat's rail, 38 lbs. per yard. Scale, ½.

iron, 6 inches long and ⅜ inch thick, was laid under each joint. The rail weighed 19 kilogrammes per metre, or 38 pounds per yard. It was 3 inches wide at the surface; the groove was 1¼ inches wide, and ⅞ inch deep; whilst the tread was only 1⅛ inches wide. The longitudinal sleepers were 4 inches wide by 6 inches deep, and were laid upon transverse sleepers, 6 inches wide and 4 inches deep, placed at 2 metres, or 6 feet 7 inches apart, between centres. The transverse sleepers were notched to receive the longitudinals, which were fixed into them by wood keys. The spikes proved to be insufficient as fasteners, for they were either broken or pulled out, probably for want of a good bearing on the sleeper, on which, it is manifest, the rail must have been displaced by the eccentric pressure of the load.

This rail was laid by the *Compagnie Générale des Omnibus*, on the lines from the Place de la Concorde to Sèvres and to Boulogne.

The next section employed, fig. 70, was that of the tram-rails laid by a private company between Sèvres and Versailles. The rail weighed 16 kilogrammes per metre, or 32 pounds per yard; it was hollowed at the lower surface, for the sake of economy of material.

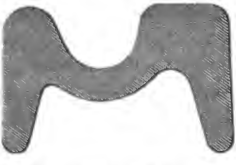


FIG. 70. Section of rail, between Sèvres and Versailles, 32 lbs. per yard. Scale, ½.

These rails, figs. 68, 69, and 70, according to M. Goschler,[1] lasted 10 years. At the end of this period the rolling surface had worn so much, that the flanges of the car-wheels lodged on the bottoms of the grooves. A rail, fig. 71, of a heavier section, weighing 46 pounds per yard, calculated to last 20 years, was employed to replace the lighter rails. A similar rail, fig. 72, has been laid by the Omnibus Company on the route between the Arc de l'Étoile and the Trône, on the *Tramways Nord*. It is 4 inches wide, and 2·16 inches deep, and has a groove 1¼ inches wide. It is fixed on a longitudinal wood sleeper, like its predecessor, by vertical bolts, through

---

[1] 'Les Chemins de Fers Nécessaires,' in the *Contes Rendus de la Société des Ingénieurs Civils*, 1873.

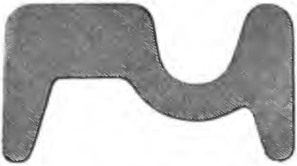


FIG. 71. Section of rail, to replace sections, figs. 69 and 70:—46 lbs. per yard. Scale, ½.

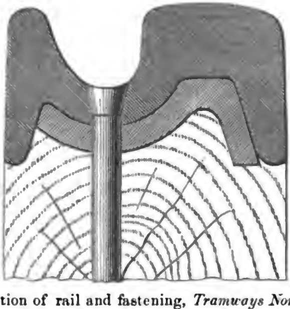


FIG. 72. Section of rail and fastening, *Tramways Nord*, 46 lbs. per yard. Scale, ½.

the bottom of the groove, with countersunk heads and nuts. The rails were rolled in lengths of 6 metres, or nearly 20 feet, and they were fished at the joints with iron plates formed to the lower surfaces of the rails.

It was early assumed that transverse sleepers were not necessary, and they were dispensed with as the lines came under repair. Cross tie-bars of wrought iron were employed instead of the sleepers, but even those were, after a time, abandoned. When the lines were laid in macadam, without any paving, the cost of maintenance was very great, due to the practice of the running of ordinary vehicles on the track of the tramway. A continual supply of new macadam was required for a width of 10 inches on each side of the rails; and, of course, the perpetual renewal of loose stone led to a greatly increased resistance on, and wear of, the tramway, occasioned by the detritus of the covering at the sides. To avoid such serious objections, the Omnibus Company replaced the macadam by paved margins next the rails in the outer portions of the system, and by a general paving on the lines within the city.

Though it appears that the first line of tramway laid—that of M. Loûbat—was laid to a gauge of 1·54 metres or 5 feet ½ inch, the tramways subsequently constructed were laid to the railway gauge, 1·44 metres, or 4 feet 8½ inches; or to 1·43 metres, or 4 feet 8⅜ inches. Uniformity of gauge was adopted, with the view of establishing communications between the railway goods-stations. The expectation was futile.

The schedule of prices adopted in 1867, for laying the tramways in macadam roads, according to M. Goschler, was as follows:—

TRAMWAYS IN PARIS.—SCHEDULE OF PRICES, 1867.

| | Francs. | £ | s. | d. | |
|---|---|---|---|---|---|
| Rails, drilled with 10 countersunk holes, per 100 kilogrammes . . . . . | 26 | 10 | 8 | 0 | per ton. |
| Bolts, or fishes, per 100 pieces | 22 | 0 | 17 | 5 | |
| Oak sleepers, longitudinal, 6 inches by 8 inches, per stère | 134 | 0 | 3 | 0 | per cu. ft. |
| Broken millstone (macadam) per cubic metre . . . . | 12 | 0 | 7 | 3 | per cu. yd. |
| Sand, per cubic metre . . | 3 | 0 | 1 | 10 | „ |
| Labour, per hour . . . . | 0·35 | | | 3·32 | per hr. |
| One-horse cart, per hour . | 1 | 0 | 0 | 9½ | „ |

On the basis of these prices, the cost per yard of the construction of a single line of tramway with the 46-pound rails, fig. 72, was as follows:—

COST PER YARD, SINGLE LINE; RAILS 46 LBS. PER YARD.

| | s. | d. |
|---|---|---|
| Rails . . . . . . . . . . | 8 | 8 |
| Longitudinal sleepers . . . . . | 2 | 10·8 |
| Shaping the sleepers . . . . . | 0 | 8·7 |
| Bolts . . . . . . . . . . | 0 | 7·7 |
| Fishes . . . . . . . . . . | 0 | 5·1 |
| Washers . . . . . . . . . . | 0 | 0·7 |
| Excavation . . . . . . . . . | 0 | 6·6 |
| Fitting together . . . . . . | 0 | 1·7 |
| Laying and packing . . . . . . | 0 | 5·2 |
| Sand . . . . . . . . . . | 0 | 1·7 |
| Broken stone . . . . . . . . | 0 | 8·7 |
| Watering and rolling . . . . . | 0 | 2·2 |
| Watching and general expenses . . . | 0 | 8·3 |
| Total . . . . . . | 16 | 4 |

Or £1,437. 6*s*. 8*d*. per mile.

The rail adopted for the *Tramways Nord*, in the Avenue de la Grande Armée, is shown in fig. 73.

The section of rail which was next laid by the *Tramways Nord*, in 1873, on the macadam road between the Porte Maillot and the Pont de Neuilly, is shown in fig. 74; adopted from English practice. The weight of the rail is 60 pounds per yard; it is bolted down through the groove to longitudinal sleepers of oak, 4 inches wide and 6 inches deep, laid on transverse sleepers, 6 inches wide and 3½ inches deep, placed at distances of 5 feet apart between centres. The cost of this way per mile of single line is estimated at £1,418, including the cost of rails, cast-iron joint-chairs, and brackets; bolts, sleepers, laying the way, watching, and sundry ex-

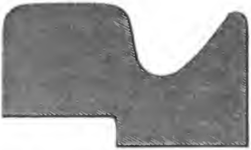


FIG. 73. Section of rail in the Avenue de la Grande Armée. Scale, ½.

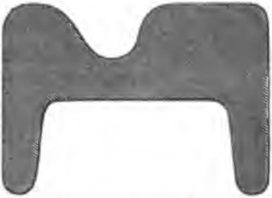


FIG. 74. Section of rail, Avenue de Neuilly, 60 lbs. per yard. Scale, ½.

penses. Though the section of rail was copied from English practice, it appears that the valuable function of the flanges, in superseding with side-fastenings the vertical holding-bolts, was not apprehended.

The whole cost of construction of the *Tramways Nord* of Paris is given in an Agenda-Dunod, 1877, from which the following summary is deduced:—

TRAMWAYS NORD.—COST PER LINEAL YARD OF DOUBLE WAY ON A PAVED ROAD.

| | £ | s. | d. |
|---|---|---|---|
| Lifting pavement and excavation | 0 | 2 | 2 |
| Paving | 1 | 7 | 7 |
| Way | 1 | 15 | 7 |
| Total | 3 | 5 | 4 |

Or £5,750 per mile.

From the balance-sheet of the Company, it appears that the total capital expenditure on these tramways amounts to £31,900 per mile.

M. Oppermann gives an analysis of the cost for working the line between Saint-Germain-des-Près and Montrouge, a part of the *Tramways Sud*, in Paris. The line is 3·12 miles in length. One car makes 20 trips in 16 hours per day, and runs (3·12 × 20=) 62·40 miles per day. Each car contains 16 passengers inside, 18 on the roof, and 10 on the platforms; in all, 44. Each car is drawn by two horses, relieved four times, making 10 horses to each car.

| | Francs |
|---|---|
| One horse costs per day for fodder | 4·50 |
| Shoeing, stabling, attendance, renewal, &c. | 1·00 |
| Total for one horse | 5·50 |
| Horse labour per car per day (5·50 × 10 =) | 55·00 |

Do. do. per mile run, ·88 franc or 8·37 pence.

The system of tramway adopted and put in execution by M. Francq, for the Versailles Tramways, in 1875, is illustrated by figs. 75, 76, and 77, with rails on a timber substructure of longitudinal sleepers laid upon transverse sleepers. The rail weighs 30½ pounds per yard; it is of a section comparatively shallow, 1⅜ inches deep, and about 3 inches wide at the sur-

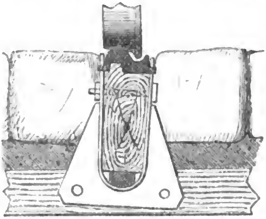


Fig. 75. Versailles Tramways:—Section of rail, &c., by M. Francq. Scale, ⅛.

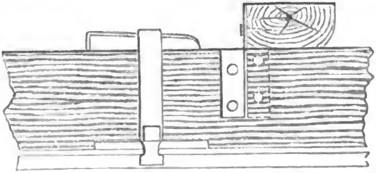


Fig. 76. Versailles Tramways:—Rail, &c., by M. Francq. Scale, ⅛.

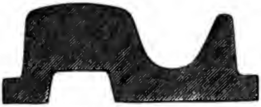


Fig. 77. Section of Versailles rail, 30½ lbs. per yard. Scale, ½.

face. It is rolled with two fillets, one on each side, projecting ¼ inch, and making a total width of 3½ inches. The rolling surface is 1 9/16 inches wide, and the groove is 1¼ inches wide. The lower surface, under the tread, is hollowed, and receives in the hollow a corresponding section of the longitudinal sleeper, which is rebated to fit the rail. The longitudinal sleepers are of fir, creosoted; they are 3 inches wide and 7 inches deep, under the soles of the rails. They are slightly inclined inwards, at an angle of 1 in 20, and laid upon transverse sleepers of oak, 6 inches wide and 3⅕ inches deep, placed at distances of 5 feet apart between centres.

The fastenings are peculiar. The lateral fillets of the rails are notched at intervals of one metre, or 40 inches between centres, to receive the two ends of an iron strap, which is doubled under the sleeper, the ends being correspondingly notched to enter the notches in the fillets, and take a bearing upon the fillets. The ends of the strap are fixed in position by a bolt and nut through the sleeper; and the strap is tightened by a hardwood wedge, driven in under the sleeper.

The longitudinal sleepers are secured to the transverse sleepers by means of a piece of iron plate, bolted to one side of each cross sleeper, and cut out and flanged to receive the longitudinal sleeper, which is spiked to it.

The objections to this—the system most recently brought out in France—are, that the fastening of the longitudinal to the transverse sleeper is in sheer, and is not durable; that the rail is too shallow, and is weak; that the means of lateral resistance of the rail to displacement upon the sleeper are insufficient; that the lateral fillets represent a waste of metal, and prevent the close-fitting of the pavement to the rail; that there are other projections which are inconvenient in the same way; and that the situation of the wedge for tightening the fastening of the rail—below the sleeper—is inconvenient for purposes of inspection and repair. This system, like many others which have failed in practice, would answer perfectly well, if it were a mere fixture; but not for resisting the stress of the rolling movement of heavy bodies.

---

### LILLE.

The tramways of Lille are constructed like level crossings for railways, with two rails and two counter-rails, enclosing at each rail a clear space sufficient for the clearance of the wheel-flanges (see

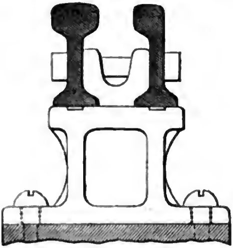


FIG. 78. Lille Tramways:—Section of rails and chair, for passenger traffic. Rail, 28·7 lbs. per yard. Scale, $\frac{1}{3}$.

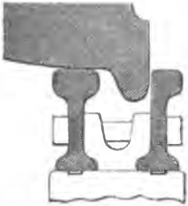


FIG. 79. Lille Tramways:—Section showing arrangement of rails for railway waggons. Scale, $\frac{1}{3}$.

fig. 78). The rail and the counter-rail are bolted to a cast-iron chair. The chairs are bedded on and screwed down to cross sleepers, at 5 feet intervals, without any intermediary longitudinal sleepers. The interspace is 1·20 inches wide for the tram-car, as in fig. 78; but, by fixing the counter-rail, so that its flat side is presented to the rail, as in fig. 79, the interspace is increased to 1·80 inches in width, for the traffic of railway waggons.

| | lbs. per yard |
|---|---|
| Weight of the rail, 3·60 inches deep . . | 28·7 |
| Do. counter-rail, do. . . . . . . | 22·5 |
| Total weight, per yard, for each rail | 51·2 |

The same system—of rail and counter-rail—has recently been adopted in the construction of the Geneva Tramways.

---

## BELGIUM.

In Brussels, the tramways are worked by four distinct companies, each company having adopted special forms of rail. The oldest line is that between Schaerbeek and the Bois de la Cambre, 4⅜ miles in length, which was completed and opened in 1869. All the other lines have been constructed since 1871. In the end of 1874, the lengths of lines of tramway open in Brussels were as follows:—

| | Miles |
|---|---|
| Belgian Street Railway . . . . . . | 8¼ |
| Compagnie Brésilienne . . . . . . | 6¾ |
| Compagnie des Voies Ferrées Belges (Bois de la Cambre) . . . . . . . | 4⅜ |
| Compagnie Becquet . . . . . . | 3¾ |
| Open in Brussels . . . . | 23⅛ |

Gauge of ways, 4 feet 8½ inches.

In other towns in Belgium, there were open as follows:—

| | Miles | | Feet | Inches |
|---|---|---|---|---|
| Anvers . . . . . | 6·16 | gauge | 4 | 5½ |
| Liège . . . . . | 4·78 | „ | 4 | 8½ |
| Gand . . . . . | 4·66 | „ | 4 | 8½ |

making a total length of about 38½ miles of tramway open in Belgium in 1874.

The way was made in double line in the first three tramways of Brussels; the fourth was made with a single way. The tramways in the other three towns were also single line, except for a small section of the tramways in Gand.

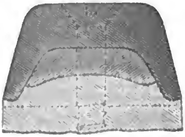


Fig. 80. Belgian Street Railway:—Section of rail laid in suburbs of Brussels, 23 lbs. per yard. Scale, ⅖.

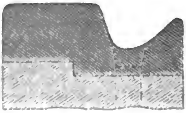


Fig. 81. Belgian Street Railway:—Section of rail laid in Brussels, 24½ lbs. per yard. Scale, ⅖.

The sections of rails employed in the tramways of Belgium are shown in figs. 80 to 90.

The interspace between two lines of way is, in Brussels, 1 metre, or 40 inches; except in narrow streets, where it is only 0·8 metre, or 32 inches. At Anvers it is 1 metre; and at Gand, 1·05 metre, or 42 inches. At Liège it is from 1½ to 1¾ metres, or from 5 feet to 5 feet 9 inches, in view of the clearance required for the passage of railway waggons.

The minimum radius of curvature permitted in any tramway is 44 metres, or 144 feet. At Brussels, the radius is usually from 100 to 130 feet; occasionally, for want of space, it is as low as 65 feet, and but rarely as low as 46 feet. At Anvers, the minimum radius is 25 metres, or 82 feet; and, at Gand, 15 metres, or 50 feet. At Liège, the lower limit is 25 metres, or 82 feet, except for the routes traversed by railway stock, where the radius is not less than 75 metres or 246 feet.

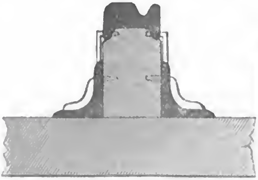


Fig. 82. Voies Ferrées Belges:— Section of rail, &c., 52 lbs. per yard. Scale, $\frac{1}{10}$.

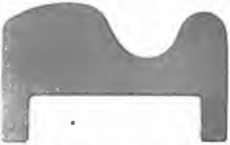


Fig. 83. Voies Ferrées Belges:— Section of rail for straight lines, 52 lbs. per yard. Scale, $\frac{2}{5}$.

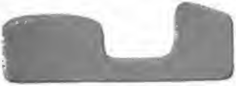


Fig. 84. Voies Ferrées Belges:— Section of inner rail for curves, 36½ lbs. per yard. Scale, $\frac{2}{5}$.

Fig. 85. Voies Ferrées Belges:— Section of outer rail for curves, 31 lbs. per yard. Scale, $\frac{2}{5}$.

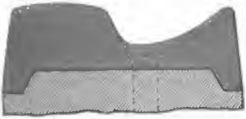


Fig. 86. Compagnie Brésilienne:— Section of rail, 34 lbs. per yard. Scale, $\frac{2}{5}$.

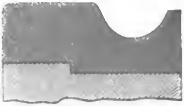


Fig. 87. Anvers:—Section of rail, 30 lbs. per yard. Scale, $\frac{2}{5}$.

The way consists generally of grooved iron rails laid on a timber substructure of longitudinal sleepers upon transverse sleepers. The only exceptions to the grooved rail are the rails used in the suburbs of Brussels and in Gand, which are formed on the principle of the 'crescent rail,' fig. 17, page 19, for which the groove is made by a gap between the rail and the pavement. Sections of the rails are shown in figs. 80 to 90, in which it is seen that, for the most part, the rails are fastened to the longitudinal sleepers by vertical screws through the grooves. The only exception is the side-fastening, by staples, employed on the 'Voies Ferrées Belges,' fig. 82. At

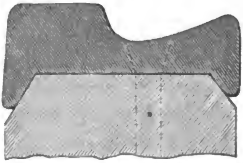


Fig. 88. Tramways d'Ixelles Etterbecq, Brussels (Compagnie Becquet):—Section of rail, 37 lbs. per yard. Scale, $\frac{3}{8}$.

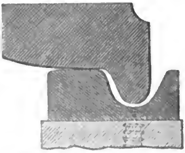


Fig. 89. Liège Tramways:—Section of rail, and tyre of railway waggon, 56 lbs. per yard. Scale, $\frac{1}{3}$.

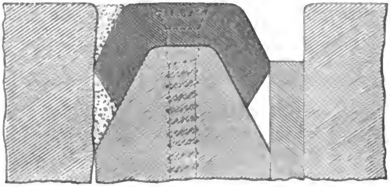


Fig. 90. Gand Tramway:—Section of rail, &c., 24 lbs. per yard. Scale, $\frac{3}{8}$.

Liège, the rail is formed with a groove 2 inches in width. The weights of the rails illustrated above are as follows:—

BELGIUM.—WEIGHT OF RAILS PER YARD.

| | lbs. |
|---|---|
| Brussels:— | |
| Belgian Street, suburbs | 23 |
| Do., in town | 24½ |
| Voies Ferrées Belges | 52 |
| Brésilienne | 34 |
| Compagnie Becquet | 37 |
| Anvers | 30 |
| Liège | 56 |
| Gand | 24 |

According to a recent publication,[1] the length of tramway in Brussels, open in the end of 1876, amounted to 45,312 metres, or 28 miles. The number of cars in service on all the lines was 84, and of horses 750. The working expenditure may be calculated approximately on the following basis:—

| | Total cost per day<br>s. d. s. d. | Miles travelled per day |
|---|---|---|
| 1 horse | 3 7 to 4 0 | 12 to 19 |
| 1 car | 16 0 to 20 0 | 60 to 80 |

These costs include the whole of the working expenses.

The first cost of Brussels tramways has been approximately as follows:—

COST OF TRAMWAYS IN BRUSSELS.

| | |
|---|---|
| Way, single line | £1,270 to £1,600 per mile. |
| Horses, including harness and accessories | £48 per horse. |
| Cars in service, including accessories | £360 per car. |
| Stables, sheds, offices, workshops, &c., per horse, effective, or on duty | £80 to £100 per horse. |

---

[1] *Revue Universelle,* September 13, 1876, page 375.

### CONSTANTINOPLE.

The tramways of Constantinople, of which M. Lebout was the engineer, were constructed with the pattern of grooved rail, weighing 46 pounds per yard, employed in the Paris tramways, fastened as in fig. 91. The rails were bolted to longitudinal

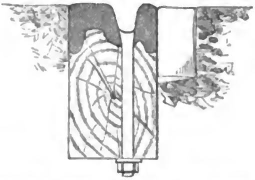


FIG. 91. Tramways at Constantinople:—Section of rail, &c., 46 lbs. per yard. Scale, $\frac{1}{6}$.

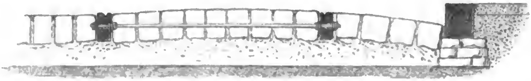


FIG. 92. Tramways of Constantinople:—Section of half-width of street and way. Scale, $\frac{1}{40}$.

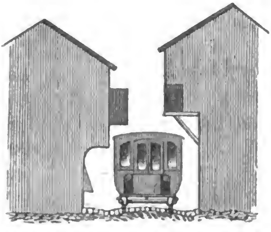


FIG. 93. Tramways of Constantinople. Section of a narrow street, with a single line of way. Scale, $\frac{1}{240}$.

sleepers, laid on a bed of sand 8 inches deep, spread on the bottom of the excavation. The longitudinal sleepers were connected by round iron tie-rods, which were passed through them, and were screwed up by nuts at both sides of the sleepers, as shown in the section of the way, fig. 92. Streets of from 13 feet to 23 feet wide were paved all the way across, as shown in fig. 93.

The rails and their accessories were, according to M. Goschler, before quoted, supplied from the Terrenoire Works, France, delivered at Constantinople, at the following prices :—

CONSTANTINOPLE TRAMWAYS.

| | Per ton<br>£ | <br>*s.* | <br>*d.* |
|---|---|---|---|
| Rails and fishes, . . £10. 1*s.* 6*d.* and | 10 | 17 | 6 |
| Bolts . . . . . . . . | 23 | 15 | 6 |
| Washers . . . . . . . | 31 | 16 | 6 |
| Tie-rods, 2 metres or 13·12 feet apart . | 33 | 9 | 0 |

The weight of material per yard of single way was as follows :—

| | Per lineal yard of way lbs. |
|---|---|
| Rails, per yard, 46 lbs. . . . . . | 92 |
| Fishes for rails, 5 lbs. each. . . . | 1·5 |
| Do., for longitudinal sleepers, 1½ lb. each | 1·38 |
| Bolts, ½ lb. each . . . . . . | 1·84 |
| Tie-rods, 13¼ lbs. each . . . . . | 3 |
| Total per yard of single way . | 100 lbs. |
| Total, if tie-rods are 2 metres, or 6·56 feet apart . . | 103 lbs. |

| | *s.* | *d.* | |
|---|---|---|---|
| Cost of laying way, including carriage, and maintenance for one year . . | 2 | 5 | per yard. |
| Cost of laying pavement . . . . | 3 | 7½ | ,, |

M. Goschler gives an analysis of the accounts of the Constantinople Tramways for 1872, which contains many instructive details.[1]

---

## MOSCOW.

The first section of the tramways of Moscow was opened in August 1874; and in 1875, a total length of 60 miles of tramway was opened for traffic. The way was designed by the engineer of the tramways, Colonel Sytenko, who commenced by rejecting the grooved rail, and adopted the Vignoles type of rail, laid on transverse sleepers, shown in figs. 94, 95. The rails are of steel, from the works at Creusot, weighing 36 pounds per yard; they are made to a height of 5 inches, to admit of the juxtaposition of paving-stones of sufficient depth above the sleepers. The paving-stones next the rails at the inner sides are cut to form a groove for the wheel-flanges. Counter-rails, it appears, have only been found necessary at the points and crossings. The rails are laid to a gauge of 5 feet, upon

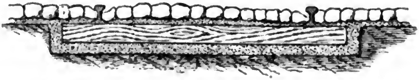


FIG. 94. Moscow Tramways:—Section of line. Scale, $\frac{1}{44}$.

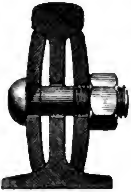


FIG. 95. Moscow Tramways:—Section of rail and fish-joint, 36 lbs. per yard. Scale, $\frac{1}{2}$.

---

[1] 'Les Chemins de Fer Nécessaires,' *Conte Rendus de la Société des Ingénieurs Civils*, 1873, page 366.

sleepers placed at intervals of 4 feet 3 inches. It is believed—and it is likely—that, on this system of way, the tractive force required is a half less than that required for the ordinary grooved rail.

---

### LEIPZIG TRAMWAYS.

The first section of the Leipzig Tramways, consisting of the Promenade Line round Leipzig, and branches to Rendwitz and Connewitz, together about six English miles in length, were opened on May 18, 1872. The line to Lindenau was opened in September of the same year, making in all 8⅔ English miles of way open for traffic in 1872. There are now, altogether, five lines open, of an aggregate length of 11·30 miles.

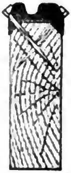


Fig. 96. Leipzig Tramways:—Section of rail, &c. Scale, ⅛.

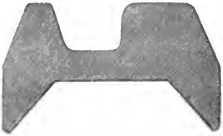


Fig. 97. Leipzig Tramways:—Section of rail, 30 lbs. per yard. Scale, ½.

The rails are laid to a gauge of 4 feet 8½ inches, on what is known as the Vienna system, which is, in fact, similar to Loûbat's way, already described, page 169. The rails are of iron, and they weigh 30 pounds per yard. They are 3 inches wide, and are formed with obliquely-faced flanges, as shown in figs. 96, 97.

They are laid on longitudinal timber sleepers, which are remarkable for their deep and narrow scantlings, being 8 inches deep, and 2¾ inches wide. They are chamfered to receive the rails, which are fastened to them by 4½-inch spikes, passed through holes punched in the flanges. The longitudinal sleepers are laid on and notched into transverse sleepers, 7 inches wide, 5 inches deep, and 6½ feet in length, placed at intervals of 6 feet between centres, and laid in ballast. The longitudinal sleepers are secured to the cross sleepers by oak wedges. When the line passed through streets already paved, the pavement was renewed for the whole width. On macadamised roads, only a narrow strip of paving was laid on each side of the rail.

---

### CASSEL TRAMWAY.

The Cassel tramway was opened on July 9, 1877, to be worked by steam locomotives, supplied by Messrs. Merryweather & Sons. The section of the rail is shown in fig. 98, with the section of the wheel-tyres of the locomotives.

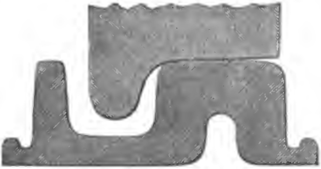


FIG. 98. Cassel Tramway :—Section of rail and wheel-tyre. Scale, ½.

### LISBON.

A concession was secured, in 1873, by Messrs. Edwin Clark, Punchard, & Co., for the construction and working of a system of tramways in Portugal, 51 miles in length—from Lisbon to Cintra, for passenger traffic, and from Lisbon to Torres Vedras, for goods and wine traffic chiefly. The tramways were made a single line, laid on the common roads; they were to be worked by tank-locomotives, with trains of passenger cars, and of goods cars, at a speed of 15 miles per hour. The ruling gradient was 1 in 20, and the quickest curves were of a radius of 25 feet.

The way consists of three parallel rails, laid on transverse sleepers. The central rail is an iron flat-footed rail, weighing 36 pounds per yard, spiked to the sleepers. The outer rails are wooden trams of oak, 8 or 9 inches wide, and 3 inches deep, laid to a gauge of 4 feet 2 inches between centres. The cross sleepers were alternately long enough to take all the rails, and short enough to take only the middle rail. The engine and the train were guided by the central rail; the weight of the train rested on the central rail, whilst the greater portion of that of the engine rested on the wooden trams, through the driving-wheels.

The engines had two steam-cylinders, 11 inches in diameter, with a stroke of 18 inches; the driving-wheels were 3 feet 9 inches in diameter, by 14 inches wide at the tyres. The pressure in the boiler was 140 lbs. per square inch. The engine was carried by two bogies, one before and one behind, arranged as bicycles, running on the central rail. The distance between the centres of the bogies was 13 feet. The weight of the engine, empty, was 11 tons 1½ cwt.;

and, in working order, 13¼ tons, of which 8½ tons was available as driving weight. According to Mr. Curry,[1] these engines were capable of taking a train of six passenger carriages, with 132 passengers, weighing altogether 22½ tons, up an incline of 1 in 20. The heaviest goods train taken up the same incline consisted of six waggons, weighing, with goods, 28½ tons.

It appears that these tramways have been abandoned.

## THE WELLINGTON CITY TRAMWAYS, NEW ZEALAND.

In the design of these tramways, fig. 99, in course of construction, to a gauge of 3 feet 6 inches, it seems that the best results of experience in Europe and America have been ignored. The rail is a flat bar 3½ inches wide, 1⅛ inches thick, grooved to a depth of ¾ inch, and leaving only ⅜ inch thickness of metal under the groove. The rail is spiked through the groove to a longitudinal sleeper 4 inches wide and 6 inches deep. The longitudinal sleepers rest on transverse sleepers, 6 inches wide, by 4 inches deep, and 5 feet long, placed at distances of 3 feet 5 inches apart between centres. The cross sleepers are fastened to the longitudinal sleepers with a small knee at each side, and one spike each way.

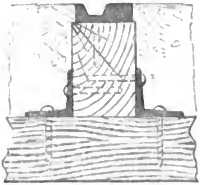


FIG. 99. Wellington City Tramways:—Section of rail, &c. Scale, ⅛.

---

[1] 'The Lisbon Steam Tramway,' a paper read March 6, 1874, at the Institution of Civil Engineers, by Mr. Matthew Curry, jun., Stud. Inst. C.E.

## CHAPTER XI.

### GENERAL CONCLUSIONS ON THE DESIGN AND CONSTRUCTION OF TRAMWAYS.

In summarising and contrasting the advantages and the deficiencies of the systems of tramway which are now in practice, it is to be borne in mind that it is possible and probable that different systems may be equally good: that they may be mechanical equivalents of each other. There are the broad distinctions between substructures of wood and those of iron, between foundations of wood and concrete and those of concrete alone, between continuous bearings and intermittent bearings for the rails. Then there are the comparative costs of different systems—first cost, and subsequently the cost of maintenance; and this leads to the question of fundamental importance—the comparative excellence and permanency of the rolling surface, and the comparative facility for traction. The motive of tramways, as substitutes for the ordinary surface of streets and roads, is centred in this one point—the reduction of tractive resistance to a minimum. There have been tramways—there may be such now—on which the resistance has been practically as great as on well-maintained streets;

these, of course, have been mistakes in engineering and in management, and it might have been better if they had not been constructed at all, but for the residuary consolation that failures are instructive, and that by a process of elimination they may lead up to success.

It is apparent, then, that a first-rate rolling surface is of the essence of a tramway—a street-railway; —and it is not well to study too closely the mere element of first cost, in the amount of which, for efficient systems of tramway, the variation is not of very considerable importance. For, as Mr. Robinson Souttar neatly puts it, 'in every well-constructed tramway, there are three constant quantities—the concrete, the paving, and the rails—making more than three-fourths of the total expenditure; the remaining fourth being represented by the longitudinal bearing.' Nor is there much difference in the cost of maintenance, which, besides, amounts to but an inconsiderable item—from 3 per cent. to 6 per cent. —of the total working expenses of a tramway. The practical value of a good rolling-surface, on the contrary, can scarcely be over-estimated; for the running and car expenses are influenced to a very great extent by the condition of the surface, and they constitute nearly two-thirds of the total working expenses.

With a perfect rolling surface, an even and durable pavement must be associated, in order that uniform levels may be preserved, not necessarily for the special business of the tramway, but for the other business of the street. A completely constructed tramway must, therefore, combine a perfect unyielding rolling-surface with a firm and durable pavement. The first condition—a perfect rolling-surface—it was impossible to fulfil so long as the rails were fastened by vertical spikes or bolts passed through the groove in the rail. But when the side-fastenings of Mr. Larsen, improved by Mr. Hopkins, were introduced, by which the rail was lapped upon the longitudinal sleeper, and was tied down by lateral staples at each side, entirely out of the reach of derangement by the strokes of the traffic, the problem was greatly simplified. The stiffness of the rail, vertically as well as laterally, was greatly augmented by the adoption of the side-fastenings. These, whilst they are placed beyond the reach of blows at the surface, are enabled, in virtue of their lateral disposition, to resist with powerful leverage the force of oblique lateral strokes:—a function in respect of which a central spike or bolt is clearly inferior to the side-staple. Vertical movement under the traffic is prevented, and the destructive action of blows from the surface is checked in the initiatory stage. The staple-fastening was so simple, and, after its introduction, so obvious, that one may wonder at the primitive combination of a flat-grooved bar, of minimum strength, with a vertical spike, which has lasted even till to-day. Let us wonder, and pass on. But before passing on, let us note that Mr. Livesey and Mr. Cockburn-Muir had from an early period perfectly well appreciated the mechanical necessity for applying the fastenings of the rail apart from the rolling surface, and had accordingly applied wedge-fastenings at the side of the rail. Their systems, as systems of iron way, have long been in advance of their time in the home countries; and though these systems have not yet entered into the domain of English practice, they have long since been established in general practice abroad.

Given, therefore, the principle of the lapped-rail, flange-rail, or box-rail, and the lateral fastening; the hard scheming is done, for the principle of the subjacent fastening is applicable to every variety of rail.

There remain for consideration the substructure and the foundation. The function of the substructure is to support the rails, and also to keep them in gauge, whilst the foundation is laid to provide a firm and uniform base for the rails and the paving conjointly, maintaining both of them to one level. In some systems of tramway, the substructure is to some extent identified with, and forms part of, the foundation. The foundation, in nearly all systems, consists wholly or mainly of concrete—an artificial stone or compound, of considerable cohesive force, admirably adapted, when properly made, for supporting dead weights on the ground, and distributing superincumbent pressure. With a broad base of concrete, the maintenance of the rails and the pavement at a uniform level may be effectually performed. A wide solid base is indispensable for the purpose, and if not already provided by nature or by previous use, it must be supplied by art.

The substructure should afford a continuous support to the rail, for the construction of a continuous bearing is simpler and better than the construction required for intermittent bearings; and, before all, the continuity of support contributes to the perfection and permanence of the rolling surface, not alone by insuring longitudinal and lateral stiffness; but also by preventing the twisting or torsion of the rail which would be caused by the eccentric pressure of the wheel on a suspended rail. Take the centre-line of the 2-inch rolling-surface of a rail 4 inches wide, as the line of insistent vertical pressure; it lies only one inch from the outer edge of the rail, and it is one inch off the central line of support. Obviously, therefore, the rail which is supported by intermittent bearings, is exposed to twisting stress between the bearings, tending to cant it sidewise; and it is required to be stiffened enough to resist such torsional stress. Besides, the same stress ultimately reaches and strains the fastenings.

An extensive area of bearing-surface between the rails, the substructure, and the foundation is not indispensable. It has been demonstrated by experience that the continuous bearing of two longitudinal sleepers, 4 inches wide, on sound concrete, is sufficient for sustaining the heaviest traffic of the streets, and maintaining the level of the rails. Two widths of 4 inches each, or 8 inches together, provide two square feet of bearing surface per lineal yard of way. This datum has been arrived at, rather than deduced, from practical results, simply because the first English rails for tramways were 4 inches in width, and the longitudinal sleepers upon which they were placed were made of the same width, in order that the granite pavement might be set close up to the rail at both sides. Very probably a less proportion of bearing surface, fairly placed, would suffice. In fact, Mr. Deacon's rail and longitudinal sleeper are only 3½ inches in width—a width which affords an area of bearing surface of not more than 1⅝ square foot per lineal yard for two sleepers. Mr. Kincaid's intermittent supports on concrete present an area of 2⅓ square feet of bearing per lineal yard. It might be difficult to prescribe the safe limit of area of bearing on concrete, for Portland-cement concrete, twelve months old, has been proved by Mr. Grant to be capable, before being crushed, of resisting loads of from 91 tons to 170 tons per square foot, according to the strength of the composition.

The mere extent of the area of bearing-surface on a foundation of concrete, therefore, is practically of no moment, and does not in itself affect, one way or another, the character of the way for durability or efficiency:—supposing, be it remembered, that the concrete is faithfully made and laid; and no other supposition, it has been proved by experience, should ever be entertained.

It is scarcely necessary to add that longitudinal sleepers of timber, in good condition, are quite capable, without suffering undue compression, of permanently supporting rails of a width of 3 or 4 inches, having a continuous bearing on the sleepers.

But the rails must also be maintained strictly to gauge by the substructure. In other words, the rails must be prevented from spreading apart, and so widening the gauge or distance between them. The maintenance of gauge is indispensable, for, if the gauge be stretched, the flanges of car-wheels, which are devised so as to run near the inner sides of the grooves, when fairly placed, bind against the bermes, or ledges, which form the inner slopes of the grooves. The effect of such a spreading is greatly to augment the frictional resistance of the cars, and, if continued far enough, to grind away the flanges and reduce their thickness, to increase the difficulty of passing the points and crossings, and, finally, to lead to the derailment of the cars. Fortunately, the derailment of a tram-car, though it may prove of great inconvenience, is a trivial matter compared with the derailment of a railway train; but the other evils of a spread of gauge are of much greater magnitude on a tramway than their analogues on a railway. It need scarcely be added that, when mechanical motive-power comes to replace the barbarity of animal-power on tramways, when railway-carriages, waggons, or locomotives, are passed over them, it will be imperative that the means of maintaining the gauge be positive, precise, and sufficient. The pavement by which the rails are enclosed affords, no doubt, material assistance in keeping the rails to gauge; but it can only be accepted as a useful auxiliary.

The method of binding the rails to gauge by transverse sleepers, to which longitudinal sleepers are fixed, by the medium of solid chairs or of brackets, or by notching together, is positive. So, also, is the method of tie-bars connecting the sleepers which carry the rails. When longitudinal sleepers are bedded in concrete for a portion of their height, the concrete forms a connection which may be said to be positive; but in practice it is treated only as auxiliary to other connections. Finally, Mr. Kincaid's chairs are solidly imbedded in blocks of concrete, which are constructed in holes formed in the ground. Nevertheless, in macadamised roads, where no paving is provided, Mr. Kincaid applies a cross tie-rod to each pair of joint-chairs; and, in the way most recently constructed in Sheffield, a solid bed of concrete has been laid for the whole width, in substitution for the isolated blocks.

Of the varieties of tie-bars applied to longitudinal sleepers, the only one that is efficient as a gauge-compelling bond, is the bar which is passed through the sleepers, upon which a nut at each end brings up the sleeper against a shoulder on the bar. For iron sleepers, notched tie-bars passed through the sleepers or blocks, and fixed into them by keys, are also positive. The cross tie-bar is a simple means of connection, and it may be convenient and sufficient for light tramways, or such as are paved with shallow paving-stones, say 4-inch cubes; for, in this case, they may be placed at a level sufficiently low to clear the paving. But, for heavier tramways, having the ordinary paving, 5, 6, or 7 inches deep, cross-ties are inconvenient, for they stand in the way of the paving, and must be bedded between courses. It must be admitted, too, that the slight bars ordinarily in use as cross-ties are not sufficiently substantial.

In fine, substantial structural connections should be provided for maintaining the level, as well as the gauge; and that those connections may be made of substantial proportions, they should be placed entirely clear of the pavement—at a lower level, of course—where there is plenty of space available. To fulfil these conditions, particularly for railway traffic, there is nothing better than the transverse sleeper, upon which longitudinal sleepers or chairs, whether of iron or of wood, may be solidly bedded and firmly fixed. The transverse sleepers are, of course, imbedded in or surrounded by concrete, together with which they constitute the foundation. The transverse connection between the two rails is thus made structurally complete; and such is the proper condition for maintaining the true lines of a tramway.

Transverse sleepers of wood give great satisfaction. Transverse sleepers of wrought iron, like Vauteren's, used on continental railways, might do well; but the wood sleeper is the better, for it possesses bulk and surface, to make and keep a place for itself, and to adhere by friction to the surrounding concrete. If anything more be desired for anchoring cross sleepers, recourse may be had to Mr. Souttar's simple expedient of bevelling the sides, and dovetailing the sleepers bodily into the concrete-base.

That a tramway should be cushioned on an elastic substance— wood—is a doctrine which has been maintained with some degree of persistency. That it should be grounded on a hard substructure—cast iron—is a doctrine maintained by others. The question of the elasticity of the material of the substructure—elasticity in the conventional sense--is a matter of perfect indifference. Wood is elastic, so also is cast iron. The action is rolling, not percussive; the speed is low, not high; and the cars, as well as the engines of the future, are, and will be, placed on springs having a wide elastic range. The pavement of streets—granite stones bedded on sand—is not, conventionally, elastic; yet it answers well for the passage of loads at the customary speed of street traffic. Elastic pavements have been tried, and they have failed. The truth is, that the depth of structure necessary for the formation of a tramway is sufficient for inducing as much elasticity—perceptible to the touch, if not to the eye—as is needful to prevent a sound structure from shaking itself loose.

The form of section of the groove in the rail is a subject deserving of careful consideration. In many of the examples of rails, which have been illustrated, it may be noted that the sides of the groove are formed with a greater degree of splay inwards than outwards, *from* the wheel than under the wheel. The motive for the greater splay has been, in some instances, to economise metal; but the economy thus effected is simply insignificant. By other designers a low slope has been adopted, with a view to the more facile extrusion of dried mud and other detritus from the groove by the wedging action of the passing wheel-flanges, than is likely to take place when the sides are vertical. There is incurred a much greater resistance to traction, when the groove is occupied by hard deposit than when it is clear; since it is inevitable that the mud and small stones or gravel, which find a lodgment in the groove, must be either expelled or trodden upon by the flanges of the wheels. It is a matter of common observation that the resistance is much increased under such conditions, and the principal reason is not far to seek: the wheels run at the same time upon two circumferences of different radii—those of the tread and the flange. Now, a square groove, by its form, resists the expulsion of detritus; and it may happen, and does frequently happen, that the resistance of the car over choked-up grooves is so much increased, that it amounts to as much as that of wheels running on common roads. In the sections of the American grooved-rails, and particularly

Mr. Light's section, it is obvious that the advantage of a widely sloping berme was appreciated by the designers of those sections. The motive of the extremely contracted grooves which have been practised—some of them not exceeding an inch in width—and which, when clear, provided little more than clearance for wheel-flanges, was the fear of the entanglement of the narrow-tyred wheels of cabs and carriages in the grooves. But it is known that the derangement of common-road vehicles, is almost wholly caused by the girding of their wheels against the outer sides of the rails, when the surface of the pavement is permitted to sink below the proper level —a cause of disorder with which the groove is not concerned.

It is further to be noted that, by the occasional grounding of the wheel-flanges over the bottom of the groove, by the intervention of mud, dust, or stones, the metal at that, the weakest point, is heavily stressed. The flanges may also ground directly on the bottom, where the table of the rail is reduced by wear, when a similar effect may be produced. It is found, in fact, that old thin rails subject to such action are spread laterally, and are occasionally split through the bottom of the groove.

The form of the groove, then, is a point of importance, and the best form is that in which the side next the rolling surface is vertical, and the whole of the slope is given to the inner side. Such is the form of the groove in the rails of Mr. Barker and Mr. Fowler.

The pavement should be specifically adapted to the tramway, and the chief concern is to construct it so that it shall maintain its level, and remain flush with the rails. A great deal of precaution has been taken for preventing the rails from sinking; whilst the pavement has been laid without sufficient permanent support. A pavement that may suffice for a street untrammelled by rails, laid on loose sand, gravel, or ashes, is not sufficient to match a pair of rigidly supported rails, carried on an unyielding foundation. There is nothing better to be done, for matching the ordinary wall-sided rail, than to bring up a solid unyielding foundation for the paving, identical with the foundation for the rails. This necessary object is fulfilled by the concreting of the subspace up to the level of the under side of the paving stones, as a bottom upon which they may, with the aid of a thin layer of sand, stand to the level. Finally, as a security that neither will water penetrate, nor sand nor mud work up, the paving sets should be grouted with an adhesive, elastic, bituminous mixture.

Adopting the conclusions just announced as standards for estimating the merits of different systems of tramway, it would appear that, upon the whole, the recently-made tramways of Glasgow afford the best example of tramway having a timber substructure, hitherto actually constructed in its entirety. Mr. Souttar's tramway contains the elements of a good system; and the provisions for offering a flat vertical bearing to the paving-stones next the rails afford facilities for readily laying the pavements. In order to effect this object, Mr. Souttar has found it necessary to retire the side-flanges inwards: contracting the width of bearing of the rail on the longitudinal sleeper, as well as cutting away the sleeper by deep rebates. To some minds, such an unusual degree of rebate, ¾ inch wide at each side, may be objectionable. But, though it slightly reduces the scantling, a sufficient bearing is left for the rail; and a better bearing, too, for the flanges, withdrawn from the flanks of the sleeper, where ordinary flange-rails may have a tendency to spring outwards. The design of the rail, also, possesses the advantage of placing the flanges more nearly under the rolling-surface at one side, and under the groove at the other side.

Of the tramways having substructures of iron the system of Mr. Kincaid, whose speciality is economy of construction, is the only one of which any lengthened experience has, as yet, been acquired in England. The isolated chairs or stools at 3-feet centres, are each levelled and set independently. In this respect, Mr. Livesey's system of coupled stools—two stools on one longitudinal sleeper—is better; for they make a structural connection, and they can be levelled and set with facility. They are, in addition, efficiently tied transversely by two tie-bars, and thus the stools and sleepers are framed together both longitudinally and transversely, and assist each other in a manner which is not available on Mr. Kincaid's system of independent chairs. These are not connected together either longitudinally or transversely, and depend for their stability each on the fixity of its own portion of concrete.

The length of the bearings of the rail on the intermediate sleepers of Mr. Kincaid and of Mr. Livesey is 3½ inches; whilst that of Mr. Cockburn-Muir is 11½ inches. It is clear enough that the long bearing on the sleeper of the last-named engineer must beneficially stiffen the rail, and he has taken advantage of such aid in adopting a longer distance apart for the sleepers, and employing a rail of less weight than those of the other engineers. The three systems may be thus brought into comparison:—

| Rails | | Weight per yard | Centres of sleepers | | Span between bearings |
|---|---|---|---|---|---|
| | | lbs. | Feet | Inches | Inches |
| Mr. Kincaid . . | iron | 43 | 3 | 0 | 32½ |
| Mr. Livesey . . | steel | 40 | 3 | 0 | 30½ |
| Mr. Cockburn-Muir . | iron | 30 | 3 | 6 | 30½ |

Now, it is to be premised that a rail may be amply strong enough, as a bearer, to support any load that may be placed upon it, whilst it may not be stiff enough: for, resistance to deflection must be the ruling consideration in the design of a tramway. Deflection should be reduced to a minimum, since vertical stiffness is the first condition for insuring a minimum tractional resistance. It is obvious, too, that vertical stiffness is an essential condition for insuring the stability of the fastenings.

The stiffness of a rail is inversely as the cube of the length, and, upon this ratio, it appears that Mr. Cockburn-Muir's rail, if it had had the same section as Mr. Kincaid's, would have been stiffer in the ratio of $32{\cdot}5^3$ to $30{\cdot}5^3$, or of 3433 to 2837, or nearly 5 to 4. That a difference of 2 inches in the span should cause a difference of a fourth or a fifth in the stiffness of a rail supported on bearings at intervals, is a noteworthy fact, and it points to the advantage of compactness of span for intermittent bearings, and of the reduction of the overhang of the rail by giving to it a considerable length of bearing surface upon the chair or stool. These advantages may be exemplified by supposing Mr. Cockburn-Muir's block-sleepers to be placed apart at 3 feet centres, the same distance apart as Mr. Kincaid's sleepers. The spans between the bearings and the relative stiffnesses of the rails—inversely as the cubes of the spans—supposing that the same rail is laid in both cases, would be as follows:—

| | Centres of sleepers | Spans between bearings | Relative stiffness |
|---|---|---|---|
| Short bearing . . | 3 feet | 32½ inches, as | 1 |
| Long bearing . . | 3 feet | 24½ inches, as | 2⅓ |

Showing that if Mr. Kincaid's rail were laid on chairs with 11½-inch bearing surfaces, it would possess 2⅓ times the stiffness, or, otherwise, the deflection of the rail between the longer bearings would be less than half of what it amounts to between the actual bearings, of shorter length. The form of Mr. Kincaid's chairs, it may be observed, lends itself readily to the extension of the bearing surface; and even if the 3½-inch bearing surface of the intermediate chairs were only doubled in length, making a 7-inch bearing, uniform with the bearing at the joint-chairs, the stiffness would be increased by nearly one-half.

It is logically deducible by the same line of argument, that with a continuous bearing under the rail, the stiffness is indefinitely greater than it can be upon bearings at intervals. But it is not to be concluded that the rail on a continuous bearing may be made indefinitely light in scantling. The rail must be of sufficient scantling to enable it to resist the wire-drawing and out-rolling action of moving loads concentrated under the wheels; to check the effects of occasional weakness of substructure; to bridge over the inevitable junctions of the substructure, even when it is nominally continuous; and to resist, also, accidental derangements of the way, and the numberless varieties of irregular stress to which tram-rails are subject.

It is to be noted, further, that Mr. Kincaid packs up the rails with concrete from sleeper to sleeper:—a construction which, indeed, is designed chiefly to fill up the vacancy, though it co-operates to some extent in supporting the rail. He has, however, gradually increased the scantling, and has substituted steel for iron as the material of his rail, so that, in his recent practice—as at Leicester—he employs rails of steel, weighing 47 pounds per yard; whilst at Sheffield, the rails recently laid on his system, weigh from 48 pounds to 50 pounds per yard. The need for specially guarding against the torsional stress of a load applied eccentrically to the rail, as a suspended rail, is provided against by the form of Mr. Kincaid's rail; of which the rolling surface stands highest at the inner edge, sloping towards the outside. The wheel, by this simple formation, takes its bearing on the inner edge of the tread, in the centre line of the rail and its supports; and so the tilting stress is obviated. It is, nevertheless, apparent that the restriction of a wheel to the narrow line of bearing surface thus provided, is objectionable, in so far as the wear of the wheel is localised at the neighbourhood of the flange, and it is matter of doubt whether the adhesion of the wheels of tramway locomotives would not be less on a narrow line than on a wider surface of contact. But, as a compensation, the frictional resistance to traction is probably also less.

Still, it is better that a uniform continuity of bearing should be provided for in the same material:—in iron, if it must be iron; in wood, if it must be wood. As a system of iron continuous bearing for the rail, Mr. Barker's system is the only one which has yet been brought into practice. His cast-iron sleeper is well designed for combining lateral strength with vertical strength; and the indented surfaces of junction of the rail and the sleeper co-operate with the central web of the rail in maintaining the rail solidly in its place upon the sleeper. The indented seating, indeed, constitutes the chief connection between the rail and the sleeper. There is but a slight structural transverse connection between the sleepers, to maintain the gauge, seeing that the sleepers themselves only rest upon shallow strips of bedding mortar let into the bottom of the excavation. True, they are filled with the same material, which may unite with the material of the bedding over which it is placed, and thus impart some degree of resisting force against lateral action; but such resistance as may be derived from this source must be relatively but slight. In this respect, the Barker sleeper—3 inches wide in the body—stands in marked contrast with the cast-iron rails of Messrs. Ransome, Deas, and Rapier, at Glasgow, which have a width of 10 inches, and are solidly packed with Portland cement-concrete, by means of which they adhere firmly to the foundation of concrete prepared for them. Mr. Lynde, nevertheless, maintains that the Barker sleeper, with its broad continuous base, 12 inches wide, and extensive area of bearing surface, which amounts to 6 square feet per lineal yard of way, requires no other means of vertical support on the hard bottoms of the Manchester streets; and that, certainly, no special means are required of keeping it to gauge, besides the stone-paving by which it is enclosed; although he provides cross tie-bars to keep the way to gauge when laid in macadam streets and roads. The Barker system has been (October 1877) at work for some months, and has so far given satisfaction. For the passage of railway traffic additional means of keeping the line to gauge would, no doubt, be required, to prevent its spreading and widening in gauge: a fate which has already overtaken the Vale of Clyde Tramways, under the traffic of railway waggons. True, the sleepers of the Vale of Clyde are of timber—flexible laterally; and those of Mr. Barker's way are of cast-iron—inflexible. But these are only inflexible within the limits of their length, and they are laid designedly as pieces independent of each other, in 3-feet lengths.

With respect to provision for supporting the pavement for the iron ways, Mr. Cockburn-Muir's is the only system in which the need for special provision is confessed and supplied—by a thorough bed of concrete. Mr. Kincaid, in whose system the use of concrete is designedly confined to the means for supporting the rail, simply lays a 3-inch bed of gravel in the bottom of the excavation; and in Mr. Fowler's application of Mr. Kincaid's system, 2 inches of sand are laid. Mr. Barker, it is true, provides lateral flanges or shelves at the lower part of the sleepers for the support of the paving-stones next the rails; and this is very efficient support, applied where it is most needed. But he leaves the other portions of the pavement to rest upon the usual bottom.

In Mr. Deacon's unique and simple system of tramway, as laid in the Inner Circle, at Liverpool, the rail and the longitudinal sleeper are tied down by a central bolt to the solid stratum of cement-concrete which forms the foundation, and is constituted a structural connection between the sleepers. The flat walls of the rail and the sleeper admit of close-paving with facility, whilst the bedding of the pavement direct on the foundation of concrete is unquestionably conducive to permanency of level and stability. But the central position of the holding-down bolt is not so favourable for opposing the greatest degree of lateral resistance to the strokes of the traffic, as the positions of ordinary outside fastenings. Besides, the bolt only holds the rail down; and should the slightest degree of vertical depression of the rail take place, the fastening would become loose, and vertical play would be set up, until, of course, the bolts were again screwed up taut. By the clearance provided round the bolt in the concrete formation, though it facilitates the process of adjustment and fastening, there is a loss of lateral holding power in the bolt, for offering resistance to lateral action; in consequence of which—particularly when the fastenings become loose—the rail and sleeper together may be rendered liable to be edged sidewise out of gauge. The central position of the groove in the rail, between two rolling surfaces, offers the advantage of a fair distribution of pressure; but the groove may be less likely to be cleared of detritus without its being lodged on the rolling surfaces.

The merits of Mr. Deacon's system will be settled by the experience to be gained from the performance of the system as laid at Liverpool.

Mr. Beloe's method of constructing a central-groove rail, in two parts—like twin-rails—by a mode of construction similar to that of the Lille tramway, combines the advantage of a divided bearing, such as it is, with external fastenings; and it utilises the whole of the material for carrying the load.

In Mr. Schenk's system, one rail only is employed as a bearing rail, the other acting as a guard, as in the Lille system. There are some good points in this system; but in their exposed position the fastenings appear likely to be loosened and damaged by the traffic.

# PART III.

## *GENERAL COST OF TRAMWAYS AND THEIR WORKING EXPENDITURE.*

THE printed reports of tramway companies contain materials for the elaboration of data for first costs, and for working expenditure. In analysing these reports, and in endeavouring to reduce to uniformity the particulars of expenditure, there is encountered the same difficulty that in past years affected the accounts of railway companies—a diversity of classification, and in some instances a confusion which one may vainly attempt to disentangle. The reports of the North Metropolitan Tramways Company present, upon the whole, the best model for the half-yearly statements of accounts: the present form of accounts having been initiated in 1873–74, at the instance of the shareholders. At a general meeting held on December 22, 1873, it was proposed to treat 'The Regulation of Railways Act, 1868,' as governing the company; to require the adoption by the directors of the system of half-yearly accounts—in many respects, no doubt, inapplicable—prescribed by that Act; and to invoke the appointment of an auditor and inspectors by the Board of Trade. The directors had, however, been advised that the Act had no application to tramway companies; and it was finally resolved that the half-yearly accounts should be assimilated, as nearly as the difference of conditions would permit, to the forms given in the Act referred to. The new model was adopted, for the first time, for the half-yearly accounts to December 31, 1873. It is of great practical moment that uniformity of accounts should be adopted by the tramway companies; for the companies have much to do before they can settle down to a steady dividend, and one of the most efficacious means of detecting waste or inefficiency, and of abolishing abuses, consists in uniformity of accounts. One of the most absurd features in tramway accounts is the fanciful charge for depreciation of plant. This weakness was cured in railway accounts many years ago, and the sooner that charges for depreciation are banished from tramway accounts, the better and simpler they will be.

The accounts of many of the tramways of the United Kingdom have been carefully analysed and classified, with the help, in some instances, of explanations afforded by the companies. The analyses are here subjoined. Particulars of horses, cars, numbers of passengers, and miles run, have been added, where they could be given. All charges which have been separately entered in the original accounts as renewals, are here carried into and merged in one sum for repair or maintenance. Charges for 'depreciation' have been carefully eschewed in the preparation of the analyses.

# CHAPTER I.

## NORTH METROPOLITAN TRAMWAYS, 1871–76.

THE North Metropolitan Tramways Company possesses the longest tramway owned by one company, and has incurred the largest capital expenditure. The following tables comprise:—

Capital expenditure.
Number and disposition of cars.
Return of working stock.
Receipts.
Passengers carried.
Working expenditure.
Averaged working expenditure for three years—1874–75–76.
Miles-run, and cost for repair of cars.
Average length and cost for maintenance of way.

The horse-power is hired from the London General Omnibus Company. The sum of 6¾*d.* per mile-run by cars is paid for horse-hire, which includes the cost for maintenance, wear and tear, and renewal of horses, wages of keepers, rent of stables, and harness. In short, as Mr. Hopkins briefly puts it, the horses are brought to the cars harnessed, and worked for 6¾*d.* per mile-run. Each car on duty, generally performs 70 miles-run per day, and requires an active stud of eleven horses, of which five pairs are on duty with the car daily, leaving one spare horse. By the terms of the contract, each pair of horses is not to work less than 14 miles, nor more than 16 miles, per day. For five pairs of horses, the mileage traversed amounts to from 70 to 75 miles per day, which gives an average of about 6½ miles per horse per day. Horses are put to the work at five years of age, and the 'life' of a horse on tram-work, according to Mr. A. G. Church, secretary and manager of the Omnibus Company, is four years.

### North Metropolitan Tramways.

*Capital Expenditure*, 1871–76.

| Year | Miles open at December 30 | Capital expenditure at December 31 | | | |
|---|---|---|---|---|---|
| | | Land, buildings, fixtures, &c. | Working stock (cars, &c.) | Total | Total per mile open |
| | Miles | £ | £ | £ | £ |
| 1871 | 9½ | — | — | 210,772 | 22,187 |
| 1872 | 20½ | — | — | 422,421 | 20,606 |
| 1873 | 27½ | 575,340 | 32,197 | 607,537 | 22,091 |
| 1874 | 29½ | 646,119 | 32,197 | 678,316 | 22,993 |
| 1875 | 30½ | 652,370 | 34,576* | 686,946 | 22,524 |
| 1876 | 30½ | 652,435 | 34,576 = 1,134 per mile | 687,011 | 22,525 |

* Note to Table.—The sum of £2,379, paid for additional stock, was charged to revenue; but it is here included as capital expenditure.

## NORTH METROPOLITAN TRAMWAYS.

*Number and Disposition of Cars*, 1872–76.

| Half-year ending | Average number on duty | | Number in good order | | Number under repair | | Total number of cars |
|---|---|---|---|---|---|---|---|
| | Cars | per cent. | Cars | per cent. | Cars | per cent. | Cars |
| Dec. 1872 . | — | — | 111 | 91·7 | 10 | 8·3 | 121 |
| June 1873 . | 79 | 50·7 | 143 | 91·2 | 13 | 8·8 | 156 |
| Dec. „ . | 108 | 69·2 | 138 | 88·5 | 18 | 11·5 | 156 |
| June 1874 . | 114 | 73·1 | 136 | 87·2 | 20 | 12·8 | 156 |
| Dec. „ . | 125 | 80·1 | 139 | 89·1 | 17 | 11·9 | 156 |
| June 1875 . | 130 | 80·3 | 151 | 93·2 | 11 | 6·8 | 162 |
| Dec. „ . | 140 | 84·3 | 147 | 88·6 | 19 | 11·4 | 166 |
| June 1876 . | 136 | 81·9 | 152 | 91·6 | 14 | 8·4 | 166 |
| Dec. „ . | 137 | 82·5 | 148 | 89·2 | 18 | 10·8 | 166 |
| | *Yearly Averages.* | | | | | | |
| Year | | | | | | | |
| 1871 | — | — | — | — | — | — | — |
| 1872 | — | — | — | — | — | — | — |
| 1873 | 94 | — | 140·5 | — | 15·5 | — | 156 |
| 1874 | 120 | — | 137·5 | — | 18·5 | — | 156 |
| 1875 | 135 | — | 149 | — | 15 | — | 164 |
| 1876 | 137 | — | 150 | — | 16 | — | 166 |
| | *Averages for the Three Years*, 1874-76. | | | | | | |
| | 130 | 80 | 145·5 | 90 | 16·5 | 10 | 162 |

*Return of Rolling Stock, as at December* 31, 1876.

| | |
|---|---|
| Large street cars, fully equipped . . . . | 124 |
| Small street cars, fully equipped . . . . | 42 |
| Omnibuses . . . . . . . . . . | 2 |
| Horses . . . . . . . . . . . | 9 |
| Carts . . . . . . . . . . . | 8 |
| Water-cart . . . . . . . . . . | 1 |
| Track trollies . . . . . . . . . | 2 |
| | 188 |

## NORTH METROPOLITAN TRAMWAYS.

### *Receipts*, 1871–76.

| Year | Miles run by cars | Receipts from traffic | Sundry receipts | Total receipts | Per cent. of capital |
|---|---|---|---|---|---|
| | Miles | £ | £ | £ | per cent. |
| 1871 | 660,874* | 43,899 | 3,507 | 47,406 | 22·5 |
| 1872 | 1,484,874 | 97,314 | 1,474 | 98,788 | 23·4 |
| 1873 | 2,457,253 | 155,220 | 2,715 | 157,935 | 26·0 |
| 1874 | 3,164,861 | 205,808 | 4,677 | 210,485 | 31·0 |
| 1875 | 3,556,684 | 234,266 | 5,495 | 239,761 | 35·0 |
| 1876 | 3,569,000 | 232,698 | 5,693 | 238,391 | 34·8 |

### *Receipts*—continued.

| Year | Average length of way open | Receipts per average mile open | Receipts per mile per week | Receipts per car | Receipts per car on duty | Receipts per mile-run |
|---|---|---|---|---|---|---|
| | Miles | £ | £ | £ | £ | Pence |
| 1871 | 5½ | 8,620 | 165·8 | — | — | 17·22 |
| 1872 | 13⅔ | 7,227 | 139·0 | — | — | 15·97 |
| 1873 | 24¼ | 6,511 | 125·2 | 995 | 1,651 | 15·42 |
| 1874 | 29½ | 7,136 | 137·2 | 1,319 | 1,715 | 15·96 |
| 1875 | 30 | 7,994 | 153·7 | 1,428 | 1,736 | 16·13 |
| 1876 | 30½ | 7,816 | 150·3 | 1,401 | 1,740 | 16·03 |

* Estimated.

### *Passengers carried*, 1871–76.

| Year | Number of passengers | | | | | Receipts from passengers | |
|---|---|---|---|---|---|---|---|
| | Total | Per car | Per car on duty | Per car on duty per day of 365 | Per mile run | Total | Per passenger |
| | Pass. | Pass. | Pass. | Pass. | Pass. | £ | Pence |
| 1871 | 4,971,646 | — | — | — | 7·52 | 43,899 | 2·12 |
| 1872 | 11,110,972 | — | — | — | 7·48 | 97,314 | 2·10 |
| 1873 | 17,977,706 | 115,300 | 191,400 | 524 | 7·32 | 155,220 | 2·07 |
| 1874 | 23,883,769 | 153,100 | 199,000 | 545 | 6·71 | 205,808 | 2·07 |
| 1875 | 27,755,917 | 169,300 | 205,600 | 563 | 7·80 | 234,266 | 2·03 |
| 1876 | 26,854,454 | 161,700 | 196,000 | 537 | 7·52 | 232,698 | 2·08 |

### NORTH METROPOLITAN TRAMWAYS.

*Working Expenditure*, 1871–76.

| | 1871 | 1872 | 1873 | 1874 | 1875 | 1876 |
|---|---|---|---|---|---|---|
| DIRECT EXPENDITURE. | £ | £ | £ | £ | £ | £ |
| Horse hire . . | 18,440 | 40,212 | 71,282 | 89,181 | 100,170 | 100,335 |
| Wages of drivers and pole-shifters . . | 2,600 | 5,769 | 10,911 | 14,021 | 14,735 | 15,119 |
| Repair of cars . . | 811 | 2,516 | 5,089 | 7,585 | 7,376 | 7,467 |
| Maintenance of way . | — | — | 1,826 | 4,237 | 4,750 | 6,738 |
| Traffic . . . . | 5,251 | 11,904 | 24,210 | 25,476 | 29,973 | 32,285 |
| { General charges . | 1,958 | 2,794 | 3,605 | 4,362 | 4,315 | 4,515 |
| { Rents . . . | (in rates, &c.) | 180<br>(in rates, &c.) | 1,564 | 1,903 | 1,600 | 1,578 |
| Direct . . | 29,060 | 63,375 | 94,487 | 146,765 | 162,919 | 168,037 |
| CONTINGENT EXPENDITURE. | £ | £ | £ | £ | £ | £ |
| Rates and taxes . | 353 | 391 | 955 | 4,146 | 4,988 | 5,808 |
| Licenses and excise duties . . . | 228 | 367 | 476 | 910 | 659 | 684 |
| Compensation . . | 353 | 852 | 988 | 1,506 | 2,055 | 747 |
| Legal and Parliamentary . . . | — | 569 | 1,796 | 4,363 | 5,077 | 2,569 |
| Contingent . | 934 | 2,179 | 4,215 | 10,925 | 12,779 | 9,808 |
| TOTAL EXPENDITURE. | 29,994 | 65,554 | 98,702 | 157,690 | 175,698 | 177,845 |
| | *d.* | *d.* | *d.* | *d.* | *d.* | *d.* |
| Do. per mile run . | 10·89 | 10·59 | 9·61 | 11·96 | 11·85 | 11·95 |
| Do. per cent. of receipts . . . | 63·3 % | 66·4 % | 62·5 % | 74·9 % | 72·3 % | 74·6 % |

*Averaged Working Expenditure for Three Years*, 1874-76.

**Miles run by cars:—10,290,545, for three years; 3,430,182 miles per year.**

| | Amount for 3 years | Amount per year | Proportional part of total expenditure | Expenditure per mile run |
|---|---|---|---|---|
| DIRECT EXPENDITURE. | £ | £ | Per cent. | Pence |
| Horse hire . . | 289,686 | 96,562 | 56·67 | 6·76 |
| Wages of drivers and shifters . . . | 43,875 | 14,625 | 8·58 | 1·02 |
| Repair of cars . . | 22,428 | 7,476 | 4·39 | ·52 |
| Maintenance of way . | 15,725 | 5,242 | 3·07 | ·37 |
| Traffic . . . . | 87,735 | 29,245 | 17·16 | 2·05 |
| { General charges . | 13,191 | 4,397 | 2·58 | ·31 |
| { Rents . . . | 5,081 | 1,693 | 0·99 | ·12 |
| | 477,721 | 159,240 | 93·45 | 11·14 |

## NORTH METROPOLITAN TRAMWAYS.

*Averaged Working Expenditure for* 1874–76—continued.

| | Amount for 3 years | Amount per year | Proportional part of total expenditure | Expenditure per mile run |
|---|---|---|---|---|
| CONTINGENT EXPENDITURE. | £ | £ | Per cent. | Pence |
| Rates and taxes . | 14,942 | 4,981 | 2·92 | ·35 |
| Licenses and excise duties . . . | 2,254 | 751 | ·44 | ·05 |
| Compensation . . | 4,308 | 1,436 | ·84 | ·10 |
| Legal and Parliamentary . . . | 12,008 | 4,003 | 2·35 | ·28 |
| | 33,512 | 11,171 | 6·55 | ·78 |
| TOTAL EXPENDITURE . | 511,233 | 170,411 | 100·00 | 11·92 |
| TOTAL RECEIPTS . | 688,637 | 229,546 | — | — |

Pence

Do. per mile run . . . . . . . . 16·06

Expenditure in parts of receipts, 74·24 per cent.

Net receipts per year do. 25·76 „ . 4·14

Do. in parts of capital expenditure . . . 8·64 „

## NORTH METROPOLITAN TRAMWAYS.

### *Miles-Run and Cost for Repair of Cars*, 1871–76.

| Year | Average number of cars | Miles run by cars | | | | | Cost for repairs | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Total | Per car | | Per car on duty | | Total | Per car | Per mile run |
| | | | Total | Per day of 365 | Total | Per day of 365 | | | |
| | Cars | Miles | Miles | Miles | Miles | Miles | £ | £ | Pence |
| 1871 | — | 660,874 | — | — | — | — | 811 | — | ·29 |
| 1872 | — | 1,484,874 | — | — | — | — | 2,516 | — | ·41 |
| 1873 | 156 | 2,457,253 | 15,700 | 43·0 | 26,140 | 71·6 | 5,089 | 32·6 | ·86 |
| 1874 | 156 | 3,164,861 | 20,300 | 55·6 | 26,370 | 72·3 | 7,584 | 48·6 | ·575 |
| 1875 | 164 | 3,556,684 | 21,700 | 59·5 | 26,350 | 72·3 | 7,376 | 45 | ·50 |
| 1876 | 166 | 3,569,000 | 21,500 | 58·9 | 26,050 | 71·4 | 7,467 | 45 | ·50 |
| | | *Averages for the Three Years*, 1874-76. | | | | | | | |
| | 162 | 3,430,182 | 21,174 | 58·0 | 26,250 | 71·9 | 7,476 | 46 | ·52 |

## NORTH METROPOLITAN TRAMWAYS.

### *Average Length and Cost for Maintenance of Way*, 1871-76.

| Year | Average length open | Cost for maintenance of way | | | |
|---|---|---|---|---|---|
| | | Total | Per mile of way | Per square yard of way * | Per mile run by cars |
| | Miles | £ | £ | Pence | Pence |
| 1871 | 5½ | — | — | — | — |
| 1872 | 13⅔ | — | — | — | — |
| 1873 | 24 | 1,826 | 75 | 1·81 | ·18 |
| 1874 | 29½ | 4,237 | 144 | 3·45 | ·32 |
| 1875 | 30 | 4,750 | 158 | 3·80 | ·32 |
| 1876 | 30½ | 6,738 | 221 | 5·30 | ·45 |
| | *Averages for the Three Years*, 1874–76. | | | | |
| | 30 | 5,242 | 175 | 4·20 | ·37 |

* Allowing 10,000 square yards per lineal mile.

# CHAPTER II.

## LONDON TRAMWAYS, 1871 76.

THE accounts of the London Tramways are here summarised similarly to the abstracts above presented for the North Metropolitan. In the table of capital expenditure, a detail is given of the expenditure at December 31, 1876, in which the item of cost for the construction of the tramway amounts to £15,010 per mile of double line. Mr. Huntingdon gives the following analysis of this cost:—

| | £ |
|---|---|
| Double line of tramways . . . . . | 3,000 |
| Paving, 6 yards wide[1] . . . . . | 8,000 |
| Engineering . . . . . . . | 1,000 |
| Extra works, &c. . . . . . . | 2,000 |
| Legal and Parliamentary charges . . | 1,000 |
| | £15,000 |

The horsing was done by the Tramway Company themselves, except the horse-power for the Brixton and Clapham lines, and for other services, which was supplied by the London General Omnibus Company, until the middle of 1873, when the Tramway Company proceeded to horse the whole of the traffic themselves, feeling confident at the time that they could keep their own horses at a cost not exceeding the amount paid for horse-power to the Omnibus Company. To enable one to judge how far their anticipations were realised, the costs per mile-run for each year, from 1872 to 1876, are here given:—

---

[1] There is probably a mistake in the amount of width here given, for the standard total width is only 17 feet, or 5⅔ yards.

| | | Horsing.<br>d. | |
|---|---|---|---|
| 1872. | Mostly on hire . . . | 5·92 | per mile run. |
| 1873. | On hire, and supplied by the Tramway Company, in nearly equal proportions . . . | 6·02 | „ |
| 1874. | Horsing done entirely by the Tramway Company . . | 6·54 | „ |
| 1875. | Ditto ditto . . | 6·84 | „ |
| 1876. | Ditto ditto . . | 6·48 | „ |

It appears that the cost was increased after the change was completed. The increase has been, to some extent, accounted for by the rise in prices of provender during the later years. The total cost for forage during the half-year ending December 31, 1876, amounted to £16,417. 3*s*. During this period, the average number of horses maintained was 1,031, and the average cost for forage was 12*s*. 3*d*. per horse per week. The following are details of the expenditure for forage:—

*Forage, Half-year to December* 31, 1876.

| | | | £ | *s.* | *d.* | £ | *s.* | *d.* |
|---|---|---|---|---|---|---|---|---|
| Maize . . | 6,811⅜ quarters | @ | 1 | 7 | 4¾ | 9,329 | 19 | 11 |
| Oats . . | 357½ „ | @ | 1 | 4 | 10¼ | 444 | 5 | 11 |
| Beans . . | 33½ „ | @ | 2 | 12 | 0 | 87 | 2 | 0 |
| Bran . . | 240 cwt. | @ | 0 | 5 | 6 | 66 | 0 | 0 |
| Hay and clover | 639 loads | @ | 6 | 7 | 10 | 4,084 | 13 | 1 |
| Straw . . | 856 „ | @ | 2 | 7 | 6 | 2,033 | 3 | 3 |
| Sawdust . | 6,801 sacks | @ | 0 | 1 | 0 | 340 | 1 | 0 |
| Sundries:—Green-stuffs, &c. . . . | | | | | | 31 | 17 | 10 |
| Total cost . . . . . . | | | | | | £16,417 | 3 | 0 |

or 12*s*. 3*d*. per horse per week.

## LONDON TRAMWAYS.

*Capital Expenditure*, 1871–76.

| Year | Miles open at December 31 | Capital expenditure at December 31 | |
|---|---|---|---|
| | | Total | Per mile |
| | Miles | £ | £ |
| 1871 | 14¼ | 263,664 | 16,610 |
| 1872 | 17¼ | 294,022 | 17,040 |
| 1873 | 18 | 336,057 | 18,670 |
| 1874 | 18 | 396,900 | 22,050 |
| 1875 | 20¼ | 421,799 | 20,830 |
| 1876 | 20¼ | 419,125 | 20,700 |

*Details of Capital Expenditure at December* 31, 1876.
*Miles opened*, 20¼.

| | £ | | £ | | | Per cent. of total. |
|---|---|---|---|---|---|---|
| Tramways opened . | 303,855, | or | 15,010 | per mile | = | 72·5 |
| Property and buildings . | 31,505, | or | 1,555 | ,, | = | 7·5 |
| Rolling stock . . | 31,733, | or | 1,567 | ,, | = | 7·6 |
| Horses . . . . | 44,093, | or | 2,177 | ,, | = | 10·5 |
| Machinery and plant . | 3,266, | or | 161 | ,, | = | ·8 |
| Harness and equipments | 3,856, | or | 190 | ,, | = | ·9 |
| Office furniture . . | 817, | or | 40 | ,, | = | ·2 |
| Total expenditure | £419,125, | or | £20,700 | ,, | | 100 |

*Number of Cars*, 1872–76.

| Half-year ending | Number in good order | | Number under repair | | Total number |
|---|---|---|---|---|---|
| | Cars | per cent. | Cars | per cent. | Cars |
| Dec. 1872 . | 96 | 94·1 | 6 | 5·9 | 102 |
| June 1873 . | ? | — | ? | — | — |
| Dec. ,, . | 96 | 90·6 | 10 | 9·4 | 106 |
| June 1874 . | 94 | 88·7 | 12 | 11·3 | 106 |
| Dec. ,, . | 116 | 92 | 10 | 8·0 | 126 |
| June 1875 . | 115 | 91·3 | 11 | 8·7 | 126 |
| Dec. ,, . | 118 | 89·4 | 14 | 10·6 | 132 |
| June 1876 . | 119 | 90 | 13 | 10 | 132 |
| Dec. ,, . | ? | — | ? | — | 132 |

## LONDON TRAMWAYS.

*Number of Cars*—continued.

| Year | Number in good order | | Number under repair | | Total number |
|---|---|---|---|---|---|
| | *Yearly Averages.* | | | | |
| | Cars | per cent. | Cars | per cent. | Cars |
| 1872 | 96 | 94·1 | 6 | 5·9 | 102 |
| 1873 | 96 | 90·6 | 10 | 9·4 | 106 |
| 1874 | 105 | 90·5 | 11 | 9·5 | 116 |
| 1875 | 116½ | 90 | 12½ | 10 | 129 |
| 1876 | 119 | 90 | 13 | 10 | 132 |
| 1876 | Number of cars on duty (second half-year) 82, being 62 per cent. of the total number. | | | | |

*Return of Rolling Stock, as at December* 31, 1876.

| | |
|---|---|
| Cars | 132 |
| Omnibuses | 15 |
| Groove-cleaners | 3 |
| Forage-vans | 4 |
| Carts | 3 |
| Brake | 1 |
| | 158 |

## LONDON TRAMWAYS.

*Receipts*, 1871–76.

| Year | Miles run by cars | Receipts from traffic | Sundry receipts | Total receipts | Per cent. of capital |
|---|---|---|---|---|---|
| | Miles | £ | £ | £ | per cent. |
| 1871 | 890,000 | 46,650 | 779 | 47,429 | 20·0 |
| 1872 | 1,859,584 | 104,910 | 648 | 105,558 | 35·9 |
| 1873 | 1,892,323 | 110,348 | 1,779 | 112,127 | 33·4 |
| 1874 | 1,953,013 | 117,416 | 2,745 | 120,161 | 30·3 |
| 1875 | 2,497,643 | 138,051 | 2,557 | 140,608 | 33·3 |
| 1876 | 2,329,703 | 134,554 | 2,020 | 136,574 | 32·6 |

## London Tramways.

*Receipts*—continued.

| Year | Average length of way open | Receipts per average mile open | Per mile per week | Per car | Per mile run |
|---|---|---|---|---|---|
| | Miles | £ | £ | £ | Pence |
| 1871 | 10 | 4,763 | 91·2 | ? | 12·79 |
| 1872 | 17¼ | 6,267 | 120·5 | 465 | 13·63 |
| 1873 | 17⅜ | 6,443 | 123·9 | 1,058 | 14·22 |
| 1874 | 18 | 6,678 | 128·4 | 1,036 | 14·77 |
| 1875 | 20¼ | 6,943 | 133·5 | 1,090 | 13·52 |
| 1876 | 20¼ | 6,746 | 129·7 | 1,035 | 14·07 |
| 1876 | Receipts per car on duty (82) | | | 1,665 | |

## London Tramways.

*Passengers Carried*, 1871–76.

| Year | Number of passengers | | | Receipts from passengers | |
|---|---|---|---|---|---|
| | Total | Per car | Per mile run | Total | Per passenger |
| | Pass. | Pass. | Pass. | £ | Pence |
| 1871 | ? | — | — | 46,650 | ? |
| 1872 | 11,098,264 | 108,800 | 5·97 | 104,910 | 2·27 |
| 1873 | 11,791,498 | 111,200 | 6·23 | 110,348 | 2·25 |
| 1874 | 13,164,025 | 113,500 | 6·74 | 117,416 | 2·14 |
| 1875 | 15,790,967 | 122,400 | 6·32 | 138,051 | 2·10 |
| 1876 | 15,595,536 | 118,100 | 6·69 | 134,554 | 2·07 |
| 1876 | Number of passengers per car on duty (82 in second half-year) . . . | | | | 190,200 |
| | Do. do. per day of 365 . | | | | 521 |

### LONDON TRAMWAYS.

### *Working Expenditure*, 1871–76.

| | 1871 | 1872 | 1873 | 1874 | 1875 | 1876 |
|---|---|---|---|---|---|---|
| DIRECT EXPENDITURE. | £ | £ | £ | £ | £ | £ |
| Horsing . . . . . | 21,564 | 45,851 | 47,446 | 53,194 | 71,175 | 62,977 |
| Drivers' and shifters' wages (estimated) . | 4,000 | 8,510 | 7,696 | 7,995 | 10,817 | 10,184 |
| Repair of cars, including buildings . | 1,020 | 4,697 | 8,149 | 4,190 | 5,221 | 6,691 |
| Maintenance of way | | | | 3,239 | 2,613 | 4,671 |
| Traffic . . . . . | 4,993 | 13,060 | 14,834 | 15,590 | 19,734 | 18,365 |
| General charges . . | 2,189 | 2,995 | 3,145 | 3,050 | 2,826 | 2,885 |
| Rents . . . . . | 1,383 | 2,080 | 2,148 | 3,624 | 5,083 | 6,547 |
| Direct . . . | 35,149 | 77,193 | 83,418 | 90,882 | 117,469 | 112,320 |
| CONTINGENT EXPENDITURE. | £ | £ | £ | £ | £ | £ |
| Rates and Taxes . . | — | 314 | 376 | 1,294 | 1,999 | 1,767 |
| Licenses and excise duties | 388 | 583 | 779 | 866 | 628 | 598 |
| Compensation . . . | 263 | 747 | 1,587 | 1,702 | 2,112 | 1,608 |
| Legal and Parliamentary | 663 | 1,277 | 1,000 | 1,150 | 1,150 | 1,728 |
| Contingent . . | 1,314 | 2,921 | 3,742 | 5,012 | 5,889 | •5,701 |
| TOTAL EXPENDITURE. | 36,463 | 80,114 | 87,160 | 95,894 | 123,358 | 118,021 |
| | d. | d. | d. | d. | d. | d. |
| Do. per mile run . . | 9·83 | 10·34 | 11·06 | 11·78 | 11·85 | 11·57 |
| Do. per cent. of receipts . | 76·9 % | 75·9 % | 77·8 % | 79·8 % | 87·8 % | 86·4 % |

### *Averaged Working Expenditure for Three Years*, 1874-76.

Miles run by cars:—6,780,359, for three years; 2,260,120 miles per year.

| | Amount for 3 years | Amount per year | Proportional part of total expenditure | Expenditure per mile-run |
|---|---|---|---|---|
| DIRECT EXPENDITURE. | £ | £ | Per cent. | Pence |
| Horsing . . . . | 187,347 | 62,449 | 55·53 | 6·63 |
| Wages of drivers and shifters (estimated) | 28,996 | 9,665 | 8·60 | 1·03 |
| Repair of cars . | 16,102 | 5,367 | 4·77 | ·57 |
| Maintenance of way . | 10,522 | 3,507 | 3·12 | ·37 |
| Traffic . . . . | 53,689 | 17,897 | 15·92 | 1·90 |
| General charges . | 8,761 | 2,921 | 2·60 | ·31 |
| Rents . . . . | 15,253 | 5,084 | 4·52 | ·54 |
| | 320,670 | 106,890 | 95·08 | 11·35 |

### LONDON TRAMWAYS.

*Averaged Working Expenditure for* 1874–76—continued.

| | Amount for 3 years | Amount per year | Proportional part of total expenditure | Expenditure per mile-run |
|---|---|---|---|---|
| CONTINGENT EXPENDITURE. | £ | £ | Per cent. | Pence |
| Rates and taxes . | 5,060 | 1,687 | 1·50 | ·18 |
| Licenses and excise duties . . . | 2,092 | 697 | ·62 | ·07 |
| Compensation . . | 5,421 | 1,807 | 1·61 | ·19 |
| Legal and Parliamentary . . . | 4,029 | 1,343 | 1·19 | ·14 |
| | 16,602 | 5,534 | 4·92 | ·59 |
| TOTAL EXPENDITURE | 337,272 | 112,424 | 100·00 | 11·94 |
| TOTAL RECEIPTS . | 397,343 | 132,448 | — | — |
| Do. per mile run . . . . . . . . | | | | Pence<br>14·06 |
| Expenditure in parts of total receipts, 84·90 per cent. | | | | |
| Net receipts do. do. 15·10 „ | | | | 2·12 |
| Do. per year, in parts of capital expenditure . . . . 2·52 „ | | | | |

## LONDON TRAMWAYS.

### *Miles-Run and Cost for Repair of Cars,* 1871–76.

| Year | Average number of cars | Miles run by cars | | | Cost for repair | | |
|---|---|---|---|---|---|---|---|
| | | Number | Per car | Per car per day of 365 | Amount | Per car | Per mile run |
| | Cars | Miles | Miles | Miles | £ | £ | Pence |
| 1871 | — | — | — | — | — | — | — |
| 1872 (½ year) | 102 | 967,664 | 9,487 | 52·0 | — | — | — |
| 1873 (½ year) | 106 | 964,785 | 9,102 | 49·9 | — | — | — |
| 1874 | 116 | 1,953,013 | 16,840 | 46·1 | 4,190 | 36 | ·52 |
| 1875 | 129 | 2,497,643 | 19,370 | 53·1 | 5,221 | 40·5 | ·50 |
| 1876 | 132 | 2,329,703 | 17,650 | 48·4 | 6,691 | 50·7 | ·71 |
| | *Averages for the Three Years,* 1874–76. | | | | | | |
| | 126 | 2,260,120 | 17,940 | 49·1 | 5,367 | 42·6 | ·57 |

## LONDON TRAMWAYS.

### *Average Length and Cost for Maintenance of Way,* 1871–76.

| Year | Average length open | Cost for maintenance of way | | | |
|---|---|---|---|---|---|
| | | Amount | Per mile of way | Per square yard of way * | Per mile run by cars |
| | Miles | £ | £ | Pence | Pence |
| 1871 | 10 | ? | — | — | — |
| 1872 | 17¼ | ? | — | — | — |
| 1873 | 17⅜ | ? | — | — | — |
| 1874 | 18 | 3,239 | 180 | 4·32 | ·40 |
| 1875 | 20¼ | 2,613 | 129 | 3·10 | ·25 |
| 1876 | 20¼ | 4,671 | 231 | 5·54 | ·48 |
| | *Averages for the Three Years,* 1874–76. | | | | |
| | 19·5 | 3,507 | 180 | 4·32 | ·37 |

* Allowing 10,000 square yards per lineal mile.

# CHAPTER III.

## LONDON STREET TRAMWAYS, 1872–76.

THE cost incurred for the tramways as laid in the streets amounted, at December 31, 1876, to upwards of £100,000, or to £18,645 per mile of double-line. The total expenditure on all the line, with buildings, horses, and plant, amounted to about £28,000 per mile.

The horse-power was hired from the London General Omnibus Company until April 1875, when the tramway company acquired their own horses and worked the lines themselves. It appears from the accounts that the cost for horse-power was the same in proportion to mileage-run, when it was hired, as when it was provided by the company themselves.

*Capital Expenditure.*

| Year | Miles open at Dec. 31 | Capital expenditure at December 31 | |
|---|---|---|---|
| | | Total | Per mile open |
| | Miles | £ | £ |
| 25 months ending Dec. 31, 1873 | — | 94,761 | — |
| 1874 | 4½ | 104,042 | 23,120 |
| 1875 | — | — | — |
| 1876 | 5½ | 153,566 | 27,921 |

## London Street Tramways.

*Details of Expenditure at December* 31, 1876.
*Miles opened,* 5½.

| | £ | | Per mile £ | | Per cent. of total |
|---|---|---|---|---|---|
| Construction of tramways, and Parliamentary, legal, engineering, and other expenses incidental thereto | 102,569, | or | 18,645 | = | 66·81 |
| Property and buildings . | 22,868, | or | 4,158 | = | 14·89 |
| Rolling stock . . . . | 10,539, | or | 1,825 | = | 6·86 |
| Horses . . . . . | 16,538, | or | 3,007 | = | 10·77 |
| Machinery . . . . | 531, | or | 96 | = | ·34 |
| Harness . . . . . | 231, | or | 42 | = | ·15 |
| Office furniture . . . . | 290, | or | 53 | = | ·20 |
| | £153,566 | | £27,916 | | 100 |

## London Street Tramways.

*Receipts,* 1873–76.

| Year | Miles run by cars | Receipts from traffic | Sundry receipts | Total receipts | Per cent. of capital |
|---|---|---|---|---|---|
| | Miles | £ | £ | £ | Per cent. |
| 25 months to Dec. 31, 1873 | — | 58,272 | 457 | 58,729 | ? |
| 1874 | 667,807 | 39,106 | 594 | 39,670 | 38·17 |
| 1875 | — | — | — | — | — |
| 1876. | 772,598 | 46,829 | 707 | 47,536 | 30·95 |

*Receipts*—continued.

| Year | Miles open | Receipts per mile open | Per mile per week | Per mile-run |
|---|---|---|---|---|
| | Miles | £ | £ | Pence |
| 25 months to Dec. 31, 1873 | — | — | — | — |
| 1874 | 4½ | 8,822 | 169·6 | 14·27 |
| 1875 | — | — | — | — |
| 1876 | 5½ | 8,644 | 166·2 | 14·77 |

## LONDON STREET TRAMWAYS.

### *Passengers Carried*, 1873–76.

| Year | Number of passengers | | | Receipts from passengers | |
|---|---|---|---|---|---|
| | Total | Per car | Per mile run | Total | Per passenger |
| | Pass. | Pass. | Pass. | £ | Pence |
| 25 months to Dec. 31, 1873 | — | — | — | 58,272 | — |
| 1874 | 4,880,983 | — | 7·30 | 39,025 | 1·92 |
| 1875 | — | — | — | — | — |
| 1876 | 5,620,880 | — | 7·27 | 46,829 | 2·00 |

### *Working Expenditure*, 1873–76.

| | 25 months to Dec. 31, 1873 | 1874 | 1876 | | |
|---|---|---|---|---|---|
| | | | Total amount | In parts of total expenditure | Per mile-run |
| DIRECT EXPENDITURE. | £ | £ | £ | per cent. | Pence |
| Horse hire . . . | 24,671 | 18,570 | — | — | — |
| Horsing by the company | — | — | 21,504 | 56·38 | 6·68 |
| Wages of drivers and pole-shifters . . . . | 5,658 | 3,287 | 4,172 | 10·94 | 1·30 |
| Repair of cars . . | 1,758 | 1,046 | 1,602 | 4·20 | ·50 |
| Maintenance of way . | 1,837 | 958 | 1,246 | 3·27 | ·39 |
| Traffic . . . . . | 6,176 | 4,795 | 5,901 | 15·47 | 1·83 |
| General Charges . . | 1,948 | 1,432 | 1,356 | 3·70 | ·43 |
| Rents, rates, and taxes | | | 907 | 2·24 | ·27 |
| Direct . . . | 42,048 | 30,088 | 36,688 | 96·22 | 11·40 |
| CONTINGENT EXPENDITURE. | | | | | |
| Rates and taxes . . | 122 | 556 | 769 | 2·02 | ·24 |
| Licenses and excise duties | 271 | 136 | 185 | ·49 | ·06 |
| Compensation . . . | 936 | 392 | 238 | ·62 | ·07 |
| Legal and Parliamentary | 607 | 393 | 250 | ·66 | ·08 |
| Contingent . . | 1,936 | 1,477 | 1,442 | 3·78 | ·45 |
| TOTAL EXPENDITURE. | 43,984 | 31,565 | 38,130 | 100·00 | 11·85 |
| | *d.* | *d.* | *d.* | | |
| Do. per mile run . . | — | 11·34 | 11·85 | — | — |
| Do. per cent. of receipts . | 74·9% | 79·6% | 80·2% | — | — |

## LONDON STREET TRAMWAYS.

### *Cost for Maintenance of Way.*

| | 1874 | 1876 |
|---|---|---|
| Length open . . . . . | 4½ miles | 5½ miles |
| Cost for maintenance . . | £958 | £1,246 |
| Ditto per mile . . . | £213 | £227 |
| Ditto per square yard of way* | 5·11 pence | 5·45 pence |
| Ditto per mile run . . | ·34 " | ·39 " |

* Allowing 10,000 square yards per lineal mile.

# CHAPTER IV.

## DUBLIN TRAMWAYS, 1872–76.

THE Dublin tramways have been horsed from the commencement, by the tramway company themselves. The expenses for horse-power in 1873 and 1874, were excessive, on account of injudicious purchases of horses, and the necessity for selling a portion of the stock and replacing it with better horses. During the last two years, 1875–6, under improved management of the horse-power, the cost for horsing amounted to 5¾*d.* per mile run by cars. As the number of horses in the stud averaged about 480 during those two years, the mileage-run, which was over a million miles per year, was performed at the rate of about six miles per horse per day—the same performance as was deduced for the horses engaged in the traffic of the North Metropolitan Tramway.

*Capital Expenditure.*

| Year | Miles open at December 31 | Capital expenditure at December 31 | |
|---|---|---|---|
| | | Total | Per mile open |
| | Miles | £ | £ |
| 1872 | 9 | 129,690 | 14,410 |
| 1873 | 15 | 213,937 | 14,262 |
| 1874 | 16 | 245,701 | 15,362 |
| 1875 | 16 | 254,481 | 15,905 |
| 1876 | 16 | 255,632 | 15,977 |

## DUBLIN TRAMWAYS.

*Details of Expenditure at December* 31, 1876.
*Miles open*, 16.

| | £ | | Per mile £ | | Per cent. of total |
|---|---|---|---|---|---|
| Tramways, equipments, rolling stock, land, buildings, &c. (including 76 cars and 5 omnibuses)* . . . . | 235,977, | or | 14,749 | = | 92·33 |
| Horses (486) . . . . | 17,364, | or | 1,085 | = | 6·79 |
| Machinery and plant . . | 900, | or | 56 | = | ·35 |
| Harness, stable implements, forges, tools . . . . | 1,090, | or | 68 | = | ·42 |
| Office furniture . . . . | 300, | or | 19 | = | ·12 |
| | £255,631, | or | £15,977 | = | 100·00 |

| | |
|---|---|
| * Say, for 76 cars, at £230 . . . . . | £17,480 |
| 5 omnibuses . . . . . . | 500 |
| | £17,980 |

*Number of Cars.*

| Half-year ending | Number in good order | | Number under repair | | Total number |
|---|---|---|---|---|---|
| | Cars | Per cent. | Cars | Per cent. | Cars |
| June 1872 . | — | — | — | — | ? |
| Dec. ,, | 43 | — | 2 | — | 45 |
| June 1873 . | 67 | 96 | 3 | 4 | 70 |
| Dec. ,, | 66 | 94 | 4 | 6 | 70 |
| June 1874 . | 62 | 89 | 8 | 11 | 70 |
| Dec. ,, | 62 | 89 | 8 | 11 | 70 |
| June 1875 . | ? | — | ? | — | 70 |
| Dec. ,, | ? | — | ? | — | 70 |
| June 1876 . | ? | — | ? | — | 70 |
| Dec. ,, | ? | — | ? | — | 76 |
| | *Yearly Averages.* | | | | |
| 1872 | — | — | — | — | ? |
| 1873 | 66½ | 95 | 3½ | 5 | 70 |
| 1874 | 62 | 89 | 8 | 11 | 70 |
| 1875 | — | — | ? | — | 70 |
| 1876 | — | — | ? | — | 73 |

## DUBLIN TRAMWAYS.

### *Traffic Receipts.*

| Year | Miles run by cars | Receipts from traffic | Sundry receipts | Total receipts | Per cent. of capital |
|---|---|---|---|---|---|
| | Miles | £ | £ | £ | Per cent. |
| 1872 | ? | 35,222 | 658 | 35,880 | 27·7 |
| 1873 | ? | 62,445 | 1,179 | 63,624 | 29·7 |
| 1874 | ? | 63,248 | 736 | 63,984 | 26·0 |
| 1875 | 1,038,724 | 69,891 | 824 | 70,715 | 27·8 |
| 1876 | 987,349 | 73,303 | 1,428 | 74,731 | 29·2 |

*Receipts*—continued.

| Year | Average length of way open | Receipts per average mile open | Per mile per week | Per car | Per mile run |
|---|---|---|---|---|---|
| | Miles | £ | £ | £ | Pence |
| 1872 | 6 | 5,980 | 115 | — | — |
| 1873 | 13 | 4,894 | 94·1 | 892 | — |
| 1874 | 16 | 3,999 | 76·9 | 903 | — |
| 1875 | 16 | 4,420 | 85 | 956 | 16·33 |
| 1876 | 16 | 4,779 | 89·8 | 1,043 | 18·17 |

## DUBLIN TRAMWAYS.

### *Passengers Carried.*

| Year | Number of passengers | | | Receipts from passengers | |
|---|---|---|---|---|---|
| | Total | Per car | Per mile-run | Total | Per passenger |
| | Pass. | Pass. | Pass. | £ | Pence |
| 1872 | 3,138,522 | 73,700* | ? | 35,222 | 2·67 |
| 1873 | 5,285,180 | 75,500 | ? | 62,445 | 2·78 |
| 1874 | 5,269,546 | 75,280 | ? | 63,248 | 2·88 |
| 1875 | 5,849,925 | 83,570 | 5·63 | 69,891 | 2·87 |
| 1876 | 6,073,637 | 86,770 | 6·15 | 73,303 | 2·90 |

---

* For second half-year.

## DUBLIN TRAMWAYS.

### *Working Expenditure.*

| | 1872 | 1873 | 1874 | 1875 | 1876 |
|---|---|---|---|---|---|
| DIRECT EXPENDITURE. | £ | £ | £ | £ | £ |
| Horsing . . . . . | 14,600 | 26,241 | 26,146 | 24,851 | 23,754 |
| Drivers' wages and traffic expenses . . . . . | 5,473 | 12,458 | 11,884 | 11,781 | 12,198 |
| Repairs of cars and buildings | 771 | 1,683 | 2,529 | 2,874 | 3,248 |
| Maintenance of way . . | — | 2,133 | 1,648 | 2,542 | 3,983 |
| General charges . . | 1,849 | 2,496 | 2,437 | 2,609 | 2,292 |
| Rents . . . . . | (in rates) | 391 | 524 | 458 | 415 |
| Direct . . . | 22,693 | 45,402 | 45,168 | 45,115 | 45,890 |
| CONTINGENT EXPENDITURE. | | | | | |
| Rates and taxes . . . | 654 | 2,293 | 2,096 | 1,776 | 1,840 |
| Compensation . . . | 120 | 437 | 298 | 1,224 | 626 |
| Legal and Parliamentary . | 543 | 1,359 | 456 | 1,251 | 845 |
| Contingent . . | 1,317 | 4,089 | 2,850 | 4,251 | 3,311 |
| TOTAL EXPENDITURE. | 24,010 | 49,491 | 48,018 | 49,366 | 49,201 |
| Do. per mile-run . . | ? | ? | ? | d.<br>11·40 | d.<br>11·96 |
| Do. per cent. of receipts . | 66·9 % | 77·8 % | 75·0 % | 69·8 % | 65·6 % |

### *Averaged Working Expenditure for Two Years,* 1875-76.

Mileage of cars, 2,026,073 for two years; 1,013,036 miles per year.

| | Amounts for two years | Amounts per year | Per cent. of total expenditure | Per mile-run |
|---|---|---|---|---|
| DIRECT EXPENDITURE: | £ | £ | Per cent. | Pence |
| Horsing . . . | 48,605 | 24,303 | 49·30 | 5·76 |
| Drivers' wages, and traffic . . . | 23,979 | 11,990 | 24·33 | 2·84 |
| Repairs of cars and buildings . . | 6,122 | 3,061 | 6·22 | ·72 |
| Maintenance of way . | 6,525 | 3,262 | 6·62 | ·77 |
| General charges . | 4,901 | 2,450 | 4·97 | ·58 |
| Rents . . . | 873 | 436 | ·89 | ·10 |
| | 91,006 | 45,503 | 92·33 | 10·78 |

## DUBLIN TRAMWAYS.

### *Averaged Working Expenditure for* 1875–76—continued.

| | Amounts for two years | Amounts per year | Per cent. of total expenditure | Per mile-run |
|---|---|---|---|---|
| CONTINGENT EXPENDITURE: | £ | £ | Per cent. | Pence |
| Rates and taxes . | 3,616 | 1,808 | 3·67 | ·43 |
| Compensation . . | 1,850 | 925 | 1·88 | ·22 |
| Legal and Parliamentary . . . . | 2,096 | 1,048 | 2·13 | ·25 |
| | 7,562 | 3,781 | 7·68 | ·90 |
| TOTAL EXPENDITURE . | 98,568 | 49,284 | 100·00 | 11·68 |
| TOTAL RECEIPTS . | 145,446 | 72,723 | — | — |

Pence per mile
Ditto per mile run . . . . . . 17·23
Expenditure in parts of receipts, 67·8 per cent.
Net receipts do. do. 33·2 „ . . 5·55
Do. per year in parts of capital expenditure . . . . 9·2 „

### *Miles-Run, and Cost for Repair of Cars.*

| Year | Average number of cars | Miles run by cars | | | Cost for repair | | |
|---|---|---|---|---|---|---|---|
| | | Number | Per car | Per car per day of 365 | Amount | Per car | Per mile-run |
| | Cars | Miles | Miles | Miles | £ | £ | Pence |
| (½-year, Dec.) 1872 | 45 | ? | — | — | 771 | (½-year) 17·1 | — |
| 1873 | 70 | ? | — | — | 1,683 | 24 | — |
| 1874 | 70 | ? | — | — | 2,529 | 36·1 | — |
| 1875 | 70 | 1,038,724 | 14,840 | 40·7 | 2,874 | 41·1 | ·66 |
| 1876 | 73 | 987,349 | 13,520 | 37·0 | 3,248 | 44·5 | ·79 |
| | *Averages for the Two Years,* 1875–76. | | | | | | |
| — | 71·5 | 1,013,036 | 14,170 | 39 | 3,061 | 42·8 | ·725 |

## DUBLIN TRAMWAYS.

*Average Length, and Cost for Maintenance of Way.*

| Year | Average length open | Cost for maintenance of way | | | |
|---|---|---|---|---|---|
| | | Amount | Per mile of way | Per square yard of way* | Per mile run by cars |
| | Miles | £ | £ | Pence | Pence |
| 1872 | 6 | — | — | — | ? |
| 1873 | 13 | 2,133 | 164 | 3·94 | ? |
| 1874 | 16 | 1,648 | 103 | 2·47 | ? |
| 1875 | 16 | 2,542 | 159 | 3·81 | ·59 |
| 1876 | 16 | 3,983 | 249 | 6·00 | ·97 |
| | *Averages for the Two Years,* 1875-76. | | | | |
| — | 16 | 3,262 | 204 | 4·90 | ·77 |

* Allowing 10,000 square yards per lineal mile.

# CHAPTER V.

## TRAMWAYS OF GLASGOW AND THE VALE OF CLYDE.

### GLASGOW CORPORATION TRAMWAYS, 1872–1876.

THE tramways of Glasgow are worked by the Glasgow Tramway and Omnibus Company. The lines are held under lease from the Corporation, for 21 years, by the company, which was formed on July 1, 1871. By the terms of the lease, the company pay to the Corporation interest at the rate of 4½ per cent. per year on the outlay: a sinking fund at the rate of about 3 per cent. per year; a mileage-rate of £150 per year for every mile of street traversed by tramways within the municipal boundary; and a reserve for the renewal of the tramways of upwards of 3 per cent. per year, amounting to from £230 to £240 per mile per year. This reserve is simply lodged in trust with the Corporation, and belongs to the company. The business of the company consisted entirely of omnibus traffic until June 30, 1872; and, till December 31, 1873, five-sixths of the traffic receipts were drawn from omnibus traffic. The following analysis of accounts is, therefore, limited to the years 1874–76, when the traffic consisted almost wholly of tramway business.

The tramways were originally worked with the stud of omnibus horses belonging to the company. But these were found unequal to the work, and they were gradually sold and replaced by more powerful horses. The cost for horsing during the three years, 1874–76, was as follows :—

| Year | d. | |
|---|---|---|
| 1874 . . . . | 6·32 | per mile run by cars. |
| 1875 . . . . | 6·41 | „ „ |
| 1876 . . . . | 5·51 | „ „ |
| Average . | 6·03*d.* | „ „ |

—showing a decided reduction for the last year, due, in part, to a fall in the price of provender, and in part, no doubt, to improvement in management. The horses are worked in studs of ten to a car, and are more hardly worked than those employed on the tramways of London, during the six week-days; but they rest on Sundays—a privilege which is unknown in the metropolis. For the years 1874 and 1876, the miles-run and the total number of horses were as follows :—

| Year | Miles-run | Average number of horses | Number of working days | Miles-run per horse per day |
|---|---|---|---|---|
| 1874 | 1,675,000 | 820 | 313 | 6·52 |
| 1876 | 2,319,000 | 1,104 | 313 | 6·71 |

—showing that the horses do more work per working day than those working in London, where six miles a day is the average per horse. But the work averaged per day, including Sundays, amounts to only 5·60 miles per day in 1874, and 5·76 miles per day in 1876.

In this connection, the daily miles-run per car on duty, in 1874, did not exceed 64 miles.

### GLASGOW CORPORATION TRAMWAYS.

*Capital Expenditure at December* 31, 1876.

Miles open, 15·15.

| December 31, 1876. | Capital | Per mile-open | Proportions in part of total |
|---|---|---|---|
| | £ | £ | Per cent. |
| Lease of the tramways . | 147,833 | 9,756 | 43·45 |
| Heritable property (buildings and ground) . | 98,295 | 6,488 | 28·89 |
| Plant and machinery . | 6,847 | 458 | 2·04 |
| Horses . . . . . | 51,177 | 3,378 | 15·04 |
| Cars . . . . . | 34,000 | 2,244 | 9·99 |
| Omnibuses . . . | 1,494 | 99 | ·44 |
| Office furniture . . | 513 | 34 | ·15 |
| Total capital . . | 340,159 | 22,457 | 100·00 |

*Traffic Receipts.*

| Year | Miles run by cars | Receipts from car traffic | Receipts from omnibus traffic | Sundry receipts | Total receipts | Per cent. of capital |
|---|---|---|---|---|---|---|
| | Miles | £ | £ | £ | £ | Per cent. |
| 1874 | 1,675,000 | 104,285 | 2,664 | 6,273 | 113,222 | — |
| 1875 | 1,851,200 | 117,463 | 292 | 5,256 | 123,011 | — |
| 1876 | 2,319,000 | 140,912 | 1,673 | 3.522 | 146,107 | 43 |

*Receipts*—continued.

| Year | Miles open | Total receipts per mile | Per mile per week | Per car | Per mile-run |
|---|---|---|---|---|---|
| | Miles | £ | £ | £ | Pence |
| 1874 | 14 | 8,086 | 155 | 1,063 | 16·22 |
| 1875 | 15·15 | 8,119 | 156 | 1,025 | 15·95 |
| 1876 | 15·15 | 9,644 | 185 | 919 | 15·12 |

## *Working Expenditure*, 1874–76.

**Total mileage run by cars, 5,845,200 for three years; 1,948,400 miles per year.**

| HEADS OF EXPENDITURE | 1874 | 1875 | 1876 | Average for 1874–76. | | |
|---|---|---|---|---|---|---|
| | | | | Amount | Per cent. of total amount | Per mile-run |
| DIRECT EXPENDITURE. | £ | £ | £ | £ | Per cent. | Pence |
| Horsing | 44,089 | 49,449 | 53,291 | 48,943 | 53·10 | 6·03 |
| Wages | 24,896 | 26,726 | 31,671 | 27,764 | 30·12 | 3·42 |
| Repairs of cars and buildings | 4,460 | 4,845 | 5,219 | 4,842 | 5·26 | ·60 |
| Maintenance of way | 4,336 | 1,495 | 2,733 | 2,855 | 3·10 | ·35 |
| General charges | 3,507 | 3,810 | 5,897 | 4,405 | 4·78 | ·54 |
| Direct | 81,288 | 86,325 | 98,811 | 88,809 | 96·36 | 10·94 |
| CONTINGENT EXPENDITURE. | | | | | | |
| Rent, rates, and taxes | 2,183 | 1,664 | 2,397 | 2,081 | 2·26 | ·26 |
| Licenses and excise duties | 630 | 164 | 350 | 381 | ·41 | ·05 |
| Compensation | 132 | 240 | 828 | 400 | ·43 | ·05 |
| Legal | 434 | 323 | 720 | 492 | ·54 | ·06 |
| Contingent | 3,379 | 2,391 | 4,295 | 3,354 | 3·64 | ·41 |
| TOTAL EXPENDITURE. | 84.677 | 88,716 | 103,106 | 92,163 | 100·00 | 11·35 |
| | d. | d. | d. | d. | | |
| Do. per mile run | 12·13 | 11·50 | 10·67 | 11·35 | — | — |
| Do. per cent. of receipts | 74·81% | 72·13% | 70·57% | 72·50% | — | — |

## *Miles-Run, and Cost for Repair of Cars.*

| Year | Average number of cars | Miles run by cars | | | Cost for repair | | |
|---|---|---|---|---|---|---|---|
| | | Number | Per car | Per car per day of 313 days | Amount | Per car | Per mile-run |
| | Cars | Miles | Miles | Miles | £ | £ | Pence |
| 1874 | 106½ | 1,675,000 | 15,790 | 50·3 | 4,460 | 41·9 | ·64 |
| 1875 | 120 | 1,851,200 | 15,430 | 49·3 | 4,845 | 40·4 | ·63 |
| 1876 | 159 | 2,319,000 | 14,590 | 46·6 | 5,219 | 32·8 | ·54 |
| | | *Averages for Three Years*, 1874–76. | | | | | |
| — | 128½ | 1,948,400 | 15,160 | 48·4 | 4,842 | 37·7 | ·60 |
| | | *For 84 Cars on Duty in* 1874. | | | | | |
| 1874 | 84 | 1,675,000 | 19,940 | 63·7 | — | — | — |

### VALE OF CLYDE TRAMWAYS, 1873–76.

Of the Vale of Clyde Tramways, the Govan section was laid out and constructed with a view to the conveyance of mineral traffic as well as passenger traffic. The mineral traffic has hitherto constituted but a very small proportion of the receipts—not more than 2½ or 3 per cent., in 1876. The Greenock section is devoted entirely to passenger traffic.

The Govan section, opened on January 1, 1873, was worked under a contract with the Glasgow Tramway Company until June 30, 1874, after which the horsing was done by another contractor.

| | |
|---|---|
| Capital expenditure, as per balance sheet, at December 31, 1876 . . . . . . | £121,840 |

*Receipts and Expenditure.*

| Year | Total receipts | Working expenditure | |
|---|---|---|---|
| | £ | £ | Per cent. |
| 1873 | 9,385 | 8,298 | 88·4 |
| 1874 | 14,544 | 11,582 | 79·6 |
| 1875 | 13,754 | 8,102 | 58·9 |
| 1876 | 15,302 | 9,869 | 64·5 |

*Year* 1876.

| | | |
|---|---|---|
| Miles open . . . . . . | 6¾ | miles |
| Miles run by 14 cars . . . | 176,251 | miles-run |
| Do. do. per car . . . . | 12,590 | „ |
| Do. do. do. per day (313) . | 40·2 | „ |
| Total receipts . . . . . . | £15,302 | |
| Do. do. per mile-open . . | £2,267 | |
| Do. do. per mile per week . | £43·6 | |
| Do. do. per car (14) . . | £1,093 | |
| Do. do. per mile-run . . | 20·84*d.* | |
| Expenditure per mile-run. . . | 13·44*d.* | |
| Net receipts per mile-run. . . | 7·40*d.* | |

# CHAPTER VI.

## EDINBURGH STREET TRAMWAYS, 1871–76.

THE tramways of the city of Edinburgh have been constructed and worked under very considerable difficulties, municipal and physical. Laid upon long and severe gradients, the Edinburgh Tramways are more difficult to work than any other system in the United Kingdom. The horse-power was supplied by contract during the first few years, in the course of which the contractor raised his terms, insomuch that on one section the company paid him the abnormal sum of 10*d.* per mile run—not unreasonable. For, though the company anticipated that not more than three horses would be required to work the system at any point, it was found that for working on the steepest gradients—on Leith Walk, North Bridge, and Portobello Road—four horses were required. In 1874 the company terminated the contract for horse-power, acquired all the horses belonging to the contractor, and commenced to horse the lines themselves. The price paid for the horses, at a valuation, was only £28 per horse. The horses were not suited for the service, and it was not until the year 1876, that the horses thus acquired at a valuation, were replaced by others suited to the work. Nevertheless, on some of the gradients the labour is excessive, and the horses are very sorely tried. From the gradients of Leith Walk, averaging 1 in 32—of which the maximum gradient is 1 in 14—the horses are shifted every few months to another and an easier section, on which there is no steeper gradient than 1 in 25. They begin to recover strength after having been worked for some time on the easier gradients, and they are again placed upon the severer inclines. 'But for such a rotation of duty, the horses,' says Dr. Wood, the chairman of the company, 'would not last at all. As it is, they last a shorter time,' he believes, 'than in most other towns, and it is extremely difficult to keep them in condition.'

The average cost for horse-power in the year 1876, worked by the company, amounted to $7\frac{3}{4}$*d.* per mile run by cars, which is probably the highest rate of cost in this country for tramway work. Naturally, the number of miles run per horse is less in Edinburgh than elsewhere. It amounts to only 5·80 miles per day of 313 in the year.

## Edinburgh Street Tramways.

### *Capital Expenditure at December* 31, 1876.

**Length of way, 13·29 miles.**

| 1876 | Amounts | Per mile of way | Per cent. of total expenditure |
|---|---|---|---|
| | £ | £ | Per cent. |
| Preliminary, legal, and Parliamentary . . | 30,110 | 2,266 | 13·64 |
| City road-trust . . | 3,000 | 226 | 1·36 |
| Way and equipments . | 136,350 | 10,256 | 61·74 |
| Stables and property . | 20,242 | 1,523 | 9·17 |
| Cars . . . . . | 11,401 | 858 | 5·17 |
| Omnibuses . . . | 1,438 | 108 | ·65 |
| Horses . . . . . | 16,909 | 1,273 | 7·66 |
| Harness . . . . | 560 | 42 | ·26 |
| Office furniture . . | 752 | 57 | ·34 |
| Totals . . . | 220,762 | 16,609 | 100·00 |

### *Traffic and Receipts for the Year* 1876.

| | |
|---|---|
| Miles run by 54 cars . . . . | 816,543 miles |
| Do. do. per car . . . . | 15,121 ,, |
| Do. do. do. per day (313) | 48·3 ,, |
| Number of passengers (8,000,000 to 9,000,000) . . . . . say | 8,500,000 pass. |
| Do. do. per cars (54) . . | 157,407 ,, |
| Do. do. per mile run . . | 10·41 ,, |
| Receipts from traffic . . . . | £60,527 |
| Do. do. sundry . . . . | £1,584 |
| Do. do. total . . . . | £62,111 |
| Do. do. per cent. of capital . | 28·13 per cent. |
| Do. do. per mile . . . . | £4,673 |
| Do. do. do. per week . | £89·9 |
| Do. do. per car (54) . . | £1,150 |
| Do. do. per mile-run . . | 18·26 pence |
| Do. do. per passenger . . | 1·71 ,, |

## EDINBURGH STREET TRAMWAYS.

### *Working Expenditure for the Year* 1876.

Mileage run by cars, 816,543 miles.

| 1876 | Amounts | Proportional part of total expenditure | Expenditure per mile-run |
|---|---|---|---|
| DIRECT EXPENDITURE. | £ | Per cent. | Pence |
| Horsing . . . | 26,363 | 58·53 | 7·75 |
| Repairs of cars and omnibuses . . . . . | 2,174 | 4·83 | ·64 |
| Maintenance of way . . | 2,707 | 6·01 | ·80 |
| Traffic (including drivers' wages) . . . . . | 7,903 | 17·54 | 2·32 |
| General charges . . . | 3,377 | 7·50 | ·99 |
| | 42,524 | 94·41 | 12·50 |
| CONTINGENT EXPENDITURE. | | | |
| Rates and taxes . . . | 675 | 1·50 | ·19 |
| Licenses . . . . . | 120 | ·27 | ·04 |
| Compensation and law expenses . . . . . | 1,719 | 3·82 | ·51 |
| | 2,514 | 5·59 | ·74 |
| TOTAL EXPENDITURE. | 45·038 | 100·00 | 13·24 |

| | | | |
|---|---|---|---|
| TOTAL RECEIPTS. | £62,111 | | Pence |
| Ditto per mile run . . . . . | | | 18·26 |
| Expenditure in parts of total receipts | | 72·52 per cent. | 13·24 |
| Net receipts ditto ditto | | 27·48 „ | 5·02 |
| Ditto ditto capital expenditure . . . . . | | 8·67 „ | |

# CHAPTER VII.

## TRAMWAYS AT LEEDS, SHEFFIELD, AND SOUTHPORT.—PROVINCIAL TRAMWAYS.

### LEEDS TRAMWAYS, 1873-1876.

*Capital Expenditure.*

| Year | Miles open at December 31 | Capital expenditure at December 31 | |
|---|---|---|---|
| | | Total | Per mile open |
| | Miles | £ | £ |
| 1873 | 8 | 83,998 | 10,500 |
| 1874 | 11 | 120,301 | 10,936 |
| 1875 | 11 | 130,571 | 11,870 |
| 1876 | 11 | 160,588 | 14,600 |

*Receipts.*

| Year | Average miles open | Receipts | | | Receipts per cent. of capital | Per mile | Per mile per week | Per car |
|---|---|---|---|---|---|---|---|---|
| | | Pass. | Sundry | Total | | | | |
| | Miles | £ | £ | £ | per cent. | £ | £ | £ |
| 1873 | 6¼ | 12,724 | 2,462 | 15,786 | 18·8 | 2,526 | 48·6 | ? |
| 1874 | 10 | 24,214 | 837 | 25,051 | 20·8 | 2,505 | 48 | 726 |
| 1875 | 11 | 37,133 | 1,568 | 38,701 | 29·6 | 3,520 | 68 | 759 |
| 1876 | 11 | 38,387 | 1,118 | 39,505 | 24·6 | 3,591 | 69 | 693 |

## LEEDS TRAMWAYS, 1873-76.

### *Working Expenditure.*

| | 1873 | 1874 | 1875 | 1876 | Average of 1875-76 | In parts of total expenditure |
|---|---|---|---|---|---|---|
| DIRECT EXPENDITURE. | £ | £ | £ | £ | £ | per cent. |
| Horsing . . . . . . | 5,016 | 10,237 | 17,653 | 18,384 | 18,018 | 61·24 |
| Traffic, including wages of drivers and pole-shifters . | 2,676 | 5,748 | 4,869 | 5,562 | 5,215 | 17·72 |
| Car, harness, and 'general' repairs . . . . . . | 677 | 868 | 2,135 | 2,208 | 2,172 | 7·38 |
| Maintenance of way . . . . | 100 | 205 | 548 | 1,339 | 944 | 3·21 |
| General (with gas and water) | 594 | 1,052 | 1,337 | 1,570 | 1,453 | 4·94 |
| Rents . . . . . . | 350 | 458 | 631 | 559 | 595 | 2·02 |
| | 9,413 | 18,568 | 27,173 | 29,622 | 28,397 | 96·50 |
| CONTINGENT EXPENDITURE. | | | | | | |
| Rates and taxes . . . .<br>Licenses and excise duties . | 263 | 577 | 686 | 736 | 711 | 2·42 |
| Legal and Parliamentary . . | — | — | 194 | 182 | 188 | ·64 |
| Sundry . . . . . . | 147 | 188 | 103 | 156 | 129 | ·44 |
| | 410 | 765 | 983 | 1,074 | 1,028 | 3·50 |
| TOTAL EXPENDITURE. | 9,823 | 19,333 | 28,156 | 30,696 | 29,425 | 100·00 |
| TOTAL RECEIPTS . . . . . . . . . | | | | | 39,103 | — |

Expenditure in parts of receipts . . . . 75·25 per cent.
Net receipts do. do. . . . . 24·75 ,,
Do. do. capital expenditure 6·65 ,,

### *Average Length and Cost for Maintenance of Way.*

| Year | Average length open | Total expenditure for maintenance | Per mile | Per square yard of way * |
|---|---|---|---|---|
| | Miles | £ | £ | Pence |
| 1873 | 6¼ | 100 | 16 | ? |
| 1874 | 10 | 205 | 20·5 | ·67 |
| 1875 | 11 | 548 | 50 | 1·63 |
| 1876 | 11 | 1,339 | 121·7 | 3·97 |

* Allowing 7,350 square yards per mile.

## SHEFFIELD TRAMWAYS, 1874-76.

### *Capital Expenditure.*

| Year | Miles open at December 31 | Capital expenditure at December 31 | |
|---|---|---|---|
| | | Total | Per mile open |
| | Miles | £ | £ |
| 1874 | 2¾ | 36,256 | 13,180 |
| 1875 | 4¾ | 37,972 | 7,994 |
| 1876 | 4¾ | 38,512 | 8,107 |

### *Receipts* (20 cars).

| Year | Average miles open | Receipts | | | Receipts per cent. of capital | Per mile | Per mile per week | Per car |
|---|---|---|---|---|---|---|---|---|
| | | Pass. | Sundry | Total | | | | |
| | Miles | £ | £ | £ | Per cent. | £ | £ | £ |
| 1874 | 2¾ | 12,489 | 175 | 12,664 | 34·9 | 4,604 | 88·5 | ? |
| 1875 | 4¾ | 15,236 | 166 | 15,402 | 40·6 | 3,242 | 62·3 | ? |
| 1876 | 4¾ | 15,144 | 130 | 15,274 | 39·6 | 3,215 | 61·8 | 764 |

### *Working Expenditure.*

| | 1874 | 1875 | 1876 |
|---|---|---|---|
| | £ | £ | £ |
| Total expenditure . . | 8,801 | 10,799 | 10,971 |
| Do. per cent. of receipts . | 69·5 % | 70·1 % | 71·8 % |
| Net receipts in parts of total receipts . . . . . | 30·5 % | 29·9 % | 28·2 % |
| Net receipts in parts of capital expenditure . . | 10·6 % | 12·2 % | 11·2 % |

## SOUTHPORT TRAMWAYS, 1874-76.

### *Capital Expenditure.*

| Year | Miles open at December 31 | Capital expenditure at December 31 | |
|---|---|---|---|
| | | Total | Per mile open |
| | Miles | £ | £ |
| 1874 | 4 | 21,422 | 5,355 |
| 1875 | 4 | 23,024 | 5,756 |
| 1876 | 4 | 26,320 | 6,580 |

*Details of Expenditure at December* 31, 1876. *Miles opened,* 4.

| | £ | | Per mile £ | | Per cent. of total |
|---|---|---|---|---|---|
| Tramways . . | 19,110, | or | 4,777 | = | 72·6 |
| Buildings . . . | 2,306, | or | 576 | = | 8·8 |
| Horses and cars . | 4,262, | or | 1,066 | = | 16·2 |
| Machinery and plant | 591, | or | 148 | = | 2·2 |
| Office furniture . | 51, | or | 13 | = | ·2 |
| | £26,320, | or | £6,580 | | 100·0 |

## SOUTHPORT TRAMWAYS, 1874–76.

### *Receipts.*

| Year | Miles open | Receipts | Per cent. of capital | Per mile | Per mile per week | Per car |
|---|---|---|---|---|---|---|
| | Miles | £ | Per cent. | £ | £ | £ |
| (15 months) 1874 | 4 | 8,051 | 30·1 | 1,610 | 31 | 920 (7 cars) |
| 1875 | 4 | 7,782 | 33·8 | 1,945 | 37 | 973 (8 ,, ) |
| 1876 | 4 | 7,941 | 30·2 | 1,985 | 38 | 722 (11 ,, ) |

### SOUTHPORT TRAMWAYS, 1874–76.

*Working Expenditure.*

| | 15 months 1874 | 1875 | 1876 |
|---|---|---|---|
| | £ | £ | £ |
| Total expenditure . . . | 5,444 | 4,299 | 5,143 |
| Do. per cent. of receipts . | 67·6 % | 55·2 % | 64·8 % |
| Net receipts in parts of total receipts . . . . . | 32·4 % | 44·8 % | 35·2 % |
| Net receipts per year in part of capital expenditure . | 9·7 % | 15·1 % | 10·6 % |

### PROVINCIAL TRAMWAYS, 1875–76.

*Capital Expenditure.*

Purchase, Construction, and Equipment, 1876.

| Name of tramway | Miles open | Capital expenditure | |
|---|---|---|---|
| | | Total | Per mile |
| | Miles | £ | £ |
| Plymouth . . . . | 2·04 | 35,983 | 17,640 |
| Cardiff . . . . . | 2·40 | 35,000 | 14,580 |
| Portsmouth . . . . | 2·24 | 42,626 | 19,030 |
| Totals . . . . | 6·68 | 113,609 | 17,010 |

*Averaged Receipts for* 1875–76.

| Name of tramway | Miles open | Receipts per year | | | Per cent. of capital | Per mile | Per mile per week |
|---|---|---|---|---|---|---|---|
| | | Pass. | Sundry | Total | | | |
| | Miles | £ | £ | £ | Per cent. | £ | £ |
| Plymouth . | 2·04 | 9,979 | 146 | 10,125 | 28·15 | 4,964 | 95·5 |
| Cardiff . . | 2·40 | 9,569 | 166 | 9,735 | 27·82 | 4,056 | 78·01 |
| Portsmouth . | 2·24 | 7,244 | 74 | 7,318 | 17·17 | 3,267 | 62·87 |
| Totals . | 6·68 | 26,792 | 386 | 27,178 | 23·93 | 4,088 | 78·61 |

## PROVINCIAL TRAMWAYS, 1875–76.

### *Yearly Working Expenditure, averaged for* 1875–76.

| | Plymouth tramway | | Cardiff tramway | | Portsmouth tramway | |
|---|---|---|---|---|---|---|
| DIRECT EXPENDITURE. | £ | Per cent. of total | £ | Per cent. of total | £ | Per cent. of total |
| Horsing, drivers, and traffic . . . . | 6,266 | 77·56 | 4,820 | 71·40 | 4,786 | 76·53 |
| Repair of cars . . | 565 | 7·00 | 581 | 8·62 | 423 | 6·77 |
| Maintenance of way | 149 | 1·85 | 228 | 3·38 | 74 | 1·19 |
| General expenses, local and in London . . | 1,040 | 12·88 | 1,017 | 15·07 | 919 | 14·68 |
| | 8,020 | 99·29 | 6,647 | 98·47 | 6,202 | 99·17 |
| CONTINGENT EXPENDITURE. | | | | | | |
| Licenses . . . . | 26 | ·32 | 16 | ·23 | 39 | ·62 |
| Compensation . . | 22 | ·28 | 35 | ·52 | 15 | ·24 |
| Legal . . . . . | 9 | ·11 | 52 | ·77 | — | — |
| | 57 | ·71 | 103 | 1·52 | 54 | ·86 |
| Total expenditure . | 8,077 | 100·00 | 6,750 | 100·00 | 6,256 | 100·00 |
| Total receipts . . . | 10,125 | — | 9,735 | — | 7,318 | — |
| Expenditure in parts of receipts . . | 79·8 % | — | 69·3 % | — | 85·5 % | — |
| Net receipts in parts of receipts . . | 20·2 % | — | 30·7 % | — | 14·5 % | — |
| Net receipts in part of capital expenditure . | 5·7 % | — | 8·5 % | — | 2·5 % | — |

# CHAPTER VIII.

## DEWSBURY, BATLEY, AND BIRSTAL TRAMWAY.

This is a single line, the construction of which has been noticed at page 82. It is 3·325 miles in length.

The following is the state of the capital expenditure at June 30, 1876:—

| | Total<br>£ | Per mile<br>£ |
|---|---|---|
| Preliminary expenses: Legal and Parliamentary, &c. | 1,622 | 487·8 |
| Construction of way | 17,327 | 5,211·0 |
| Do. stables | 2,507 | 754·0 |
| Office furniture | 50 | 15·0 |
| Saddlery | 100 | 30·1 |
| 40 horses | 1,705 | 512·8 |
| 7 cars | 1,273 | 382·9 |
| Omnibus | 123 | 37·0 |
| Plant:—Steam-engine, corn mill, hay-chopper, shafting, tools, &c. | 413 | 124·2 |
| Actual cost | 25,120 | 7,555·0 |
| Auditors | 10 | 3·0 |
| Total cost | 25,130 | 7,[illegible]8·0 |

The amount for construction of way consists of these items:—

| | £ | Per mile<br>£ |
|---|---|---|
| Paid to contractor . . . . . | 16,481 | 4,957 |
| Compensation to the Corporation of Batley . . . . £500<br>Do. do. Dewsbury £100 | 600 | 180 |
| Paid to engineers and clerk of works | 246 | 74 |
| | £17,327 | £5,211 |

Two of the cars are constructed to carry 40 passengers, 20 inside and 20 outside, and they weigh 2¼ tons each. The remaining five cars carry 32 passengers, 16 inside and 16 outside, and they weigh 1¾ tons each. The wheels are 30 inches in diameter, and at a distance of 5½ feet apart between the axles. The ordinary traffic is worked by the smaller cars. On Saturday evenings, and other special occasions, the larger cars are also employed.

The whole number of 40 horses is equivalent to eight horses per car in ordinary running; the extra cars are worked by the same stock of horses. The horses are occasionally rested during the week, and on every Sunday, on which day the traffic is suspended. 'It is certainly a very good road,' says Mr. Truswell, the manager and secretary, 'but, nevertheless, too much on granite sets,'—that is to say, for the good of the horses. Only three pairs of horses are run per day with each car on duty, and one pair is in reserve to supply the place of sick horses and for rest days. Each pair of horses on active duty runs one-third of the day.

The number of miles run by cars during the year 1875–76, was 106,500, run on 313 days. This mileage is equivalent to—

340¼ miles per day.
67 do. do. per car on regular duty (5).
22⅓ do. do. per pair of horses.
21,300 do. per year per car on regular duty.

The receipts from traffic for the years 1875–76 were:—

| | £ |
|---|---|
| Fares . . . . . . | 4,945 |
| Sundry . . . . . . | 123 |
| | £5,068 |

being equivalent to—

20·17 per cent. of the capital expenditure at June 30, 1876.
£1,524 per mile open, for the year.
£29·3 per mile open, per week.
£1,013·6 per car on duty daily.
11·42 pence per mile run.

### DEWSBURY, BATLEY, AND BIRSTAL TRAMWAY.

*Working Expenditure for the Year ending June* 31, 1876.

Miles run by cars, 106,500.

| | Total | Proportional part of total expenditure | Per mile-run |
|---|---|---|---|
| DIRECT EXPENDITURE. | £ | Per cent. | Pence |
| Horsing . . . . | 2,629 | 69·35 | 5·92 |
| Drivers' wages . . | 322 | 8·49 | ·73 |
| Repair of cars . . | 26 | ·69 | ·06 |
| Maintenance of way . | 80 | 2·10 | ·18 |
| Traffic . . . . | 405 | 10·68 | ·91 |
| General charges . . | 210 | 5·54 | ·47 |
| | 3,672 | 96·85 | 8·27 |

### DEWSBURY, BATLEY, AND BIRSTAL TRAMWAY.

*Working Expenditure for the Year ending June* 31, 1876—continued.

| | Total | Proportional part of total expenditure | Per mile-run |
|---|---|---|---|
| CONTINGENT EXPENDITURE. | £ | Per cent. | Pence |
| Rent, rates, and taxes | 104·2 | 2·75 | ·23 |
| Licenses | 14·7 | ·39 | ·04 |
| | 119 | 3·14 | ·27 |
| TOTAL EXPENDITURE | £3,791 | 100·00 | 8·54 |
| TOTAL RECEIPTS | £5,068 | — | 11·42 |
| Expenditure in parts of receipts | 74·8 per cent. | | |
| Net receipts do. do. | 25·2 „ | | 2·88 |

The items of the expenditure for horsing are as follows:—

| | £ | s. | d. |
|---|---|---|---|
| Provender | 1,735 | 1 | 3 |
| Renewal of horses, being the cost for fresh horses, less the proceeds of the sale of horses | 253 | 17 | 9 |
| Shoeing | 200 | 16 | 6 |
| Stablemen, wages | 323 | 0 | 0 |
| Veterinary services | 30 | 0 | 0 |
| General labour | 70 | 16 | 6 |
| General repairs | 15 | 16 | 6 |
| | £2,629 | 8 | 6 |

Each horse is allowed 17 pounds of corn per day, composed of oats, peas, maize, and bran; with 12 pounds of chopped hay, occasionally mixed with straw. To each horse is given also 1½ pounds of linseed, after having been steeped in cold water for 24 hours, stirred about, and given as a drink. 'It is the finest thing I know of,' says Mr. Truswell, 'and a frequent change in the food of a horse has most beneficial results. This does not receive the attention it deserves; it is invaluable to the health and well-being of the horse.' The quantities of provender consumed during the year were as follows:—

| | | | £ | s. | d. | |
|---|---|---|---|---|---|---|
| Hay . | 63 tons 13 cwt. . | @ | 8 | 5 | 0 | per ton |
| Straw . | 33 tons 12 cwt. 2 qrs. | @ | 4 | 0 | 0 | ,, |
| Oats . | 367 quarters . . | @ | 1 | 7 | 3 | per qr. |
| Maize . | 40 ,, . . | @ | 1 | 10 | 0 | ,, |
| Beans . | 40 ,, . . | @ | 2 | 2 | 0 | ,, |
| Peas . | 52 ,, . . | @ | 2 | 2 | 0 | ,, |
| Linseed . | 21 ,, . . | @ | 3 | 10 | 0 | ,, |
| Bran . | 140 packs, of 17 stone 4 lbs. | @ | 0 | 15 | 0 | ,, |
| Green clover | 55 tons 2 cwt. . . | @ | 2 | 0 | 0 | per ton |
| Carrots . | 7 tons 3 cwt. . . | @ | 2 | 15 | 0 | ,, |
| Grazing . | . . . . . | | 35 | 2 | 0 | |

'Some horses are finished for our purpose in twelve months, whilst others will last five or six years; but there is the fact that we run ours much farther and faster in a day than many companies do, which will go a great way to account for their not lasting very long. But I do make it a practice to have them well attended to.'

The shoes of the horses last, on an average, from eight to ten days. In exceptional instances, horses have required to be re-shod every four days.

# CHAPTER IX.

## THE LONDON GENERAL OMNIBUS COMPANY.

THE management and the experience of the London General Omnibus Company has been long-continued and successful; and it is well to epitomise some of the results of their experience, drawn from the half-yearly Reports of the Company for the years 1875–76. A considerable proportion of the business of the Company consists in supplying horse-power to the North Metropolitan Tramways Company. It is not possible, therefore, to deduce from the accounts the net cost for omnibus service. The following epitome contains all that can usefully be abstracted for comparison with the accounts of tramway companies:—

| CAPITAL IN PROPERTY:— | 1875<br>£ | | 1876<br>£ |
|---|---|---|---|
| Leases and buildings. . | 73,808 | ... | 73,808 |
| Stock - in - trade:— Omnibuses, horses, harness, goodwill, and appurtenances . . . . | 522,116 | ... | 521,540 |
| Total . . | £595,924 | ... | £595,348 |

| | 1875 | 1876 |
|---|---|---|
| | No. | No. |
| **OMNIBUSES:—** | | |
| Miles run | 11,619,606 | 11,806,956 |
| Average number of omnibuses on daily duty on week days | 564 | 568 |
| Do. do. on Sundays | 460 | 470 |
| Do. do. for 7 days a week | 550 | 554 |
| Miles run per omnibus on duty, per year | 21,130 | 21,320 |
| Number of passengers carried by omnibuses | 49,720,038 | 51,157,946 |
| Do. do. per mile-run | 4·28 | 4·33 |
| Average number of horses | 7,913 | 7,893 |
| **RECEIPTS:—** | | |
| | £ | £ |
| Ordinary omnibus traffic and hire | 537,905 | 544,056 |
| Horsing tramway cars | 106,194 | 100,573 |
| Manure and advertising | 9,447 | 9,012 |
| Total receipts | £653,546 | £653,641 |
| Receipts per cent. of capital in property at the end of the year | 109·6 % | 109·8 % |
| Receipts from omnibus traffic per omnibus on duty | £978 | £982 |
| Do. do. per day (365) | £1,474 | £1,491 |
| Do. do. per omnibus per day | £2 13*s.* 7*d.* | £2 13*s.* 6½*d.* |
| Do. do. per mile-run | 11·11*d.* | 11·05*d.* |
| Do. do. per passenger | 2·60*d.* | 2·55*d.* |

### *Averaged Working Expenditure for Two Years,* 1875–76.

Miles-run per year, 11,713,281.

| | Per year | |
|---|---|---|
| **DIRECT EXPENDITURE:—** | | |
| | £ | |
| Horsing, including renewal of horses (7,903 horses) | 404,618 | |
| Do. do. per horse | | £51·2 |

| | Per year<br>£ | |
|---|---|---|
| Maintenance of omnibuses, and aprons | 29,431 | |
| Do. do. per omnibus on duty (552) | | £53·3 |
| Do. do. per mile-run (11,713,281) | | 0·60*d.* |
| Traffic charges, including wages of drivers and conductors | 115,883 | |
| General charges, including rents | 27,410 | |
| Total | £577,342 | |
| Contingent Expenditure:— | £ | |
| Rates and taxes | 2,776 | |
| Excise duties and licenses | 2,586 | |
| Compensation and law charges connected therewith | 3,620 | Per mile run.<br>or ·047*d.* |
| | £8,982 | |
| Total expenditure | £586,324 | |

The numbers of new omnibuses that were constructed as renewals of omnibus stock in the course of two years, were as follows:—

| | | |
|---|---|---|
| Half-year ending | June 1875 | 9 |
| Ditto | December 1875 | 11 |
| Ditto | June 1876 | 14 |
| Ditto | December 1876 | 13 |
| New omnibuses in two years | | 47 |

The mileage run by omnibuses during the same period amounted to 23,426,562 miles, equivalent to 498,440 miles per omnibus replaced. The life of an omnibus is therefore deducible, in round numbers, as 500,000 miles. Again, the average annual number of miles run per omnibus on daily duty is 21,225 miles. If it be taken at 21,000 miles, a round number, the average life in years of the omnibuses, supposing that they were on duty every day continuously, would be 24 years. But, necessarily, they are off duty for repair from time to time; and though the accounts do not show how many surplus omnibuses there are in the stock, it may be assumed for present purposes that 80 per cent. of the whole number is on daily duty, and 20 per cent., or a fourth more, is in reserve and under repair. Adding, correspondingly, a fourth to the number of years above found, 30 years is arrived at as the actual life in time of an omnibus.

The length of the lives of the horses contrasts unpleasantly with the length of life of the omnibuses. The average total number of horses, and the number of carcases and living horses sold when unfit for the duty, during the year 1875–76, were as follows:—

| Year | Average total number of horses | Number sold | Per cent. of total |
|---|---|---|---|
| 1875 | 7,913 | 1,889 | 23·9 % |
| 1876 | 7,893 | 1,774 | 22·5 % |
| Averages | 7,903 | 1,832 | 23·2 % |

showing that upwards of 23 per cent. of the stock of horses are sold and, of course, replaced per year. From these data, it follows that the whole of the stock of horses is renewed in

$$\frac{100}{23{\cdot}2} = 4{\cdot}31 \text{ years;}$$

and that thus the life of an omnibus horse is 4·31 years:—varying from 4·2 years in 1875, to 4·44 years in 1876.

Mr. A. G. Church, the general manager and secretary, states, on an extended basis of experience, that the life of a horse varies from 4 years to 4½ years in the service:—4 years on tramway service, and 4½ years on omnibus service. The shorter life of the tramway horse is easily accounted for by the greater effort required to start a tramway-car, in consequence of the greater mass, rigidity, and weight, compared with the condition of an omnibus; together with the greater frequency of the stoppages to which the tram-car is subject, arising from the greater number of passengers carried by the car, and from the number of stoppages incurred in addition by the occasional blockage of the tramway by other vehicles. The frequently repeated efforts required of the horses to start the cars, tell disastrously upon their condition; for, although the resistance to a tram-car on a tramway is much less per ton than the resistance to an omnibus on a common road, yet the effort of traction required to start a tram-car is much greater than that for an omnibus. The greater frequency of the stoppages of the tram-car for passengers than of the omnibus is proved by the greater number of passengers per mile run by the car, which amounts to about 7½ passengers per mile on the North Metropolitan Tramway—worked by the Omnibus Company—and to only 4·30 passengers per mile by the omnibus. It is very probable, taking into account extra stoppages by the car and by the omnibus, that the former is stopped and started at least twice as frequently as the latter.

There is a significance in the correspondence between the number of horses sold and replaced, and the receipts from omnibus traffic and the horsing of tramway-cars, in the two years 1875 and 1876. Thus, in 1876, the receipts from omnibus traffic were about £6,000 greater, and those from tramways were about the same amount less than in 1875. The easement was made apparent in the smaller number of horses sold in 1876:—it was 1,774 as against 1,889 sold in the previous year.

The proportional number of carcases and living horses sold during the year ending June 30, 1876, were:—

| | | | |
|---|---|---|---|
| 1,208 carcases, | or 65 | per cent. |
| 676 living horses, | or 35 | „ |
| 1,884 sold | 100 | |

showing that two-thirds of the horses that were sold, either died or were worn out in the service, and that a third were sold as only fit for agricultural work:—too weak, or afflicted with bent knees. From more extended data, Mr. Church states that the proportion of carcases and living horses sold are about 60 per cent. and 40 per cent. The horses are purchased at about the age of five years, for about £40 each; and they are sold when worn out for £9 or £10. For agricultural service they fetch, on re-sale, sometimes as much as £16, £17, or £18.

The horses are fed almost entirely with maize: oats as a staple of food has been abandoned. The following are the quantities and the costs of provender, for the half-year ending December 31, 1876, including the cost of preparation, cartage, lighterage, and expenses at the depôts:—

| Quarters | | | £ | *s.* | *d.* | £ | *s.* | *d.* |
|---|---|---|---|---|---|---|---|---|
| 1,419 | oats . . . . | @ | 1 | 3 | 9 | 1,685 | 18 | 5 |
| 49,179 | maize . . . . | @ | 1 | 8 | 2 | 69,317 | 13 | 6 |
| 921 | beans . . . . | @ | 2 | 8 | 7 | 2,237 | 7 | 9 |
| 3,197 | bran . . . . | @ | 0 | 11 | 1 | 1,769 | 19 | 7 |
| Loads | | | | | | | | |
| 4,399 | hay and clover . | @ | 6 | 6 | 6 | 27,828 | 11 | 11 |
| 8,618 | straw . . . . | @ | 2 | 6 | 3 | 19,947 | 1 | 6 |
| | Sundry and grass farm . . . | | | | | 141 | 17 | 0 |
| | | | | | | £122,928 | 9 | 8 |

The weight of the grain consumed was as follows:—

| | | tons | cwt. | qrs. | lbs. |
|---|---|---|---|---|---|
| Oats, | 1,419 quarters | 192 | 11 | 2 | 8 |
| Maize, | 49,179 ,, | 10,538 | 7 | 0 | 16 |
| Beans, | 921 ,, | 205 | 11 | 2 | 12 |
| | Total weight | 10,936 | 10 | 1 | 8 |

The average cost of provender consumed by each stud, including the expenses in connection with the provender department, was £174.

It appears, from the foregoing statements, that the total cost for maintenance and renewal of horses was £51. 4*s*. per year, or about £1 per week.

# CHAPTER X.

## ANALYSIS OF THE CAPITAL COST OF ENGLISH TRAMWAYS.

The capital accounts of tramway companies bear evidence of extremely unequal and disproportionate expenditure, including, in many instances at least, absurd and arbitrary charges for nominal damages or fancied privileges. The most absurdly unjust charge imposed upon urban tramway companies is the cost for paving the line of tramway, which extends to a width of nearly six yards in case of double lines, and amounts, in round numbers, to 10,000 square yards per lineal mile. Allowing 12*s.* per square yard as the cost for the pavement, exclusive of foundation, there is forestalled, for the cost for paving alone, an item of £6,000 per mile of double line—a charge which clearly ought to come home to the municipality.

There is not much difference in the costs of tramways. As Mr. Souttar remarks, 'a tramway will cost practically the same, whatever system is adopted; and it is a question of condition, not of system.' . . . 'It cannot be too clearly understood that the cost of a tramway is only slightly affected by the particular system on which it is laid, but materially by the weight of rail and quality of paving and concrete that the circumstances render advisable.'[1]

The annexed abstracts of the actual net costs of various tramways, already described, demonstrate the force of these remarks. Separate items are given for the three leading elements of cost—excavation and concrete foundation, way, and paving. Though in some instances the distribution of cost is only approximated, it shows how limited a proportion of cost is incurred by the way itself, which lies between £1,000 and £1,500 per mile, in round numbers, when the rails are of steel or of rolled iron. The variation of cost, here tabulated, is, of course,

*Net Cost of Tramways, per mile of way, single line.*

Foundation, way, and paving (points and crossings not included).

| Locality or designation | Rails:— Material and weight per yard | Excavation and concrete | Way, including laying | Paving | Total cost |
|---|---|---|---|---|---|
| | | £ | £ | £ | £ |
| 1. London Tramways . | Iron, 50 lbs. | 306 | 1,500 | 3,564 | 5,460 |
| 2. Edinburgh . . . | Iron, 52 lbs. | 1,174 | 1,555 | 2,712 | 5,441 |
| 3. Dundee . . . . | Iron, 60 lbs. | 2,658 | | 2,420 | 5,078 |
| 4. Glasgow, 1st contract . | | 3,249 | | 1,484 | 4,733 |
| 5. Do. 6th do. . | Iron, 60 lbs. | 682 | 1,655 | 3,069 | 5,406 |
| 6. Bristol, Kincaid . . | Iron, 43 lbs. | 484 | 1,265 | 2,640 | 4,389 |
| 7. Leicester, do. . . | Steel, 47 lbs. | 315 | 1,149 | 1,300 | 2,764 |
| 8. Southport, Beloe . . | Iron, 40 lbs. | 567 | 1,505 | 1,697 | 3,769 |
| 9. Wirral, do. . . | Iron, 52 lbs. | 470 | 1,318 | 1,580 | 3,368 |
| 10. Manchester, Barker . | Steel, 40 lbs. | 2,320 | | 2,640 | 4,960 |
| 11. Liverpool, Deacon . | Steel, 61 lbs. | 1,261 | 1,460 | 1,804 | 4,525 |
| 12. Souttar . . . . | Steel, 55 lbs. | 997 | 1,418 | 2,712 | 5,122 |
| 13. Glasgow Harbour, Ransome, Deas, & Rapier | Cast iron 203 lbs. | 611 | 2,420 | 2,496 | 5,527 |
| 14. Livesey . . . . | Steel, 40 lbs. | ? | 1,178 | ? | ? |
| 15. Cockburn-Muir . . | Iron, 30 lbs. | ? | 1,046 | ? | ? |
| 16. Dowson . . . . | Iron, 30 lbs. | ? | 1,025 | ? | ? |
| Averages, excluding No. 13 . . . . | | 695 | 1,389 | 2,291 | 4,585 |

NOTE TO TABLE.—For Nos. 8, 9, 10, 11, the cost for paving has been reckoned at the rate of 12*s*. per square yard.

---

[1] *Proceedings of the Institution of Civil Engineers*, vol. l. page 51.

affected as much by variety of prices as by the material and the quantities. But, taking averages, the elements of net cost are as follows:—

*Averaged Net Cost of Way, single line, with rails of steel or of rolled iron.*

| | Single line | Double line |
|---|---|---|
| Excavation and Concrete | 695 | 1,390 |
| Way | 1,389 | 2,768 |
| Paving | 2,291 | 4,582 |

To the net cost are to be added legal, parliamentary, engineering, and other charges. Turning to the statements of accounts for eleven tramways, which have been analysed, exclusive of the Vale of Clyde system, comprising 130½ miles of streets laid with tramways, nearly all double way, the average total cost is £18,707 per mile. For four of these lines—the London, London Street, Edinburgh Street, and Dewsbury—of which the average cost amounted to £19,321 per mile of street, the following is an approximate analysis of the capital expenditure:—

*Capital Cost.*
*Length of Lines, 42½ miles.*

| | Per mile £ | Per cent. of total |
|---|---|---|
| Tramways opened | 14,040 | 72·66 |
| Property, buildings, machinery, and plant | 1,920 | 9·93 |
| Office furniture | 45 | ·23 |
| Rolling stock | 1,334 | 6·90 |
| Horses | 1,870 | 9·68 |
| Harness and equipments | 112 | ·58 |
| Total | £19,321 | 100·00 |

The components of the cost for 'tramways opened' have been given for the London Tramways, at page 220, and are here repeated for direct reference:—

| | Per mile |
|---|---|
| Double line of tramways | £3,000 |
| Paving | 8,000 |
| Engineering | 1,000 |
| Extra works, &c. | 2,000 |
| Legal and Parliamentary charges | 1,000 |
| Total per mile | £15,000 |

Averages do not reveal extremes; and it may be stated that the capital cost varies from £28,000 per mile for the London Street Tramways, to £6,580 for the Southport Tramways.

# CHAPTER XI.

## SUMMARY RECEIPTS OF TRAMWAYS.

The receipts of tramways afford truly remarkable evidence of their popularity and their utility. On the Glasgow Corporation Tramways the receipts amounted, in 1876, to £185 per mile open per week, for six days a week; which far exceeds the relative amount received by the busiest railway company in England, the London and North Western. In 1865 the receipts of this company amounted to just 111*l.* per mile open per week.

*Receipts of Tramways in the year* 1876.

Comprising 12 Companies, occupying 137 miles of streets and roads.

| Name of tramway | Receipts per mile of way | Per mile per week | Per car | Per mile-run | Per cent. of capital cost |
|---|---|---|---|---|---|
| | £ | £ | £ | Pence | Per cent. |
| North Metropolitan | 7,816 | 150·3 | 1,401 | 16·03 | 34·8 |
| London | 6,746 | 129·7 | 1,035 | 14·07 | 32·6 |
| London Street | 8,[illegible]44 | 166·2 | — | 14·77 | 31·0 |
| Dublin | 4,779 | 89·8 | 1,046 | 18·17 | 29·2 |
| Glasgow Corporation | 9,644 | 185 | 919 | 15·12 | 43·0 |
| Vale of Clyde | 2,267 | 43·6 | 1,093 | 20·84 | — |
| Edinburgh Street | 4,673 | 89·9 | 1,150 | 18·26 | 28·13 |
| Leeds | 3,591 | 69 | 693 | — | 24·6 |
| Sheffield | 3,215 | 61·8 | 764 | — | 39·6 |
| Southport | 1,985 | 38 | 722 | — | 30·2 |
| Dewsbury, Batley, and Birstal | 1,524 | 29·3 | 715 | 11·42 | 20·17 |
| Provincial | 4,088 | 78·6 | — | — | 23·93 |
| Averages | 5,945 | 114·3 | 1,070 | 15·73 | 32·8 |

| | | |
|---|---|---|
| Receipts per car on duty:— | North Metropolitan | £1,740 |
| | London | 1,665 |
| | Dewsbury | 1,014 |

The lowest amount of earnings was £29, taken by the Dewsbury, Batley, and Birstal line, in the first year of its existence, after having been fully opened. The gross receipts, in 1876, as may be seen in the preceding table, amount to 35 per cent. or over one-third of the capital cost, on the North Metropolitan Tramway; on the Glasgow Corporation Tramways they amount to 43 per cent. The following are the averages of the receipts given in the table:—

*Receipts in* 1876.

| | |
|---|---|
| Per mile of way . . . . . | £5,945 |
| Per mile per week . . . . | 114·3 |
| Per car . . . . . . . | 1,070 |
| Per mile-run . . . . . | 15·73 pence |
| Per cent. of capital cost . . . | 33 per cent. |

The maximum rate of fares authorised by Act of Parliament is a penny per mile; though in general a minimum charge of 3*d.* is allowed for distances less than three miles. But these charges have probably never been levied. On the contrary, the fare does not usually exceed one penny per mile; on many lines the rates of fares range lower than this—on some lines only ½*d.* per mile, on special routes.

# CHAPTER XII.

## GENERAL ANALYSIS OF THE WORKING EXPENDITURE OF TRAMWAYS.

The heavy preponderance of the cost for horse-power on tramways has been occasionally pointed out in the preceding analyses of accounts. It may be recalled here for some of the companies:—

*Horsing Expenditure.*

| | Per cent. of total expenditure | Per mile run |
|---|---|---|
| North Metropolitan, 1874–76 . . | 56·67 | 6·76*d*. |
| London, 1874–76 . . . . . | 55·53 | 6·63 |
| London Street, 1876 . . . . . | 56·38 | 6·68 |
| Dublin, 1875–76 . . . . . . | 49·30 | 5·76 |
| Glasgow, 1874–76 . . . . . | 53·10 | 6·03 |
| Edinburgh Street, 1875–76 . . . . | 58·53 | 7·75 |
| Dewsbury, Batley, and Birstal, 1875–76 | 69·35 | 5·92 |

The expenditure for horse-power varies from 50 to 60 per cent. and it may be taken at an average of 55 per cent. of the receipts, and at 6½*d*. per mile-run by cars drawn by a pair of horses. The excessive cost for horse-power at Edinburgh—7¾*d*. per mile-run—has already been accounted for by the excessive steepness of the gradients.

The expenditure for drivers' and pole-shifters' wages, and for working the traffic, was as follows:—

*Driving and Traffic Expenses.*

| | Drivers' &c. wages | | | Traffic | | |
|---|---|---|---|---|---|---|
| | Per cent. | | Per mile-run<br>*d.* | Per cent. | | Per mile-run<br>*d.* |
| North Metropolitan, 1874–76 . . | 8·58 | or | 1·02 | 17·16 | or | 2·05 |
| London, 1874–76 . | 8·60 | ,, | 1·03 | 15·92 | ,, | 1·90 |
| London Street, 1876 | 10·94 | ,, | 1·30 | 15·47 | ,, | 1·83 |
| Dublin, 1875–76 | (in traffic) | | — | 24·33 | ,, | 2·84 |
| Glasgow Corporation, 1874–76 . . | ,, | | — | 30·12 | ,, | 3·42 |
| Edinburgh Street, 1875–76 . . | ,, | | — | 17·54 | ,, | 2·32 |
| Dewsbury, &c. . | 8·49 | or | ·73 | 10·68 | ,, | ·91 |

The expenditure for drivers' and pole-shifters' wages may be taken at 9 per cent. of the receipts, or 1*d.* per mile run; and for the traffic department, 17 per cent. or nearly 2*d.* per mile-run.

Placing these, the three principal items, together, they constitute four-fifths of the whole expenditure:—

| | Per cent. of total expenditure | Per mile-run<br>*d.* |
|---|---|---|
| Horsing . . . . . . . . | 55 | 6½ |
| Drivers' and pole-shifters' wages . | 9 | 1 |
| Traffic expenses . . . . . | 17 | 2 |
| | — | — |
| | 81 | 9½ |

The remaining items of expenditure—for repair of cars, maintenance of way, general charges, and contingent expenses—constitute the remaining 19 per cent. or 2¼*d.* per mile-run. The following are the separate items:—

*Minor Expenses.*

| | Cars | Way | General | Contingent |
|---|---|---|---|---|
| | *d.* | *d.* | *d.* | *d.* |
| North Metropolitan | ·52 | ·37 | ·43 | ·78 |
| London | ·57 | ·37 | ·85 | ·59 |
| London Street | ·50 | ·39 | ·70 | ·45 |
| Dublin | ·72 | ·77 | ·68 | ·90 |
| Glasgow Corporation | ·60 | ·35 | ·54 | ·41 |
| Edinburgh Street | ·64 | ·80 | ·99 | ·74 |
| Dewsbury, &c. | ·06 | ·18 | ·47 | ·27 |

None of these items amounts to so much as a penny per mile-run. The lines are not old enough yet to have attained to their normal rates of cost for maintenance of the cars and of the way, excepting, perhaps, the Dublin Tramways, which are the oldest in the list. But it is not probable that these items of expenditure will amount in the future to a penny per mile-run for any of the lines. Mr. Hopkins has estimated that, for the maintenance of the way of the North Metropolitan Tramway, the sum of £350 per mile is sufficient in perpetuity. As the mileage run in 1876 amounted to 117,000 miles per mile of way, that sum would be equivalent to ·72*d.* or less than ¾*d.* per mile-run.

*Total Expenses.*

The total expenditure on tramways averages 11¾*d.* per mile-run, or, say, 1*s.*; and it is 75 per cent. of the gross receipts, which average, say, 16*d.* per mile-run.

# PART IV.

## *TRAMWAY CARS.*

## CHAPTER I.

### HISTORICAL NOTICE OF TRAMWAY CARS.

The earliest tramway cars, specially constructed for the modern tramway, were those which were constructed in 1831, for the New York and Haarlem Street Railway, of which the first section, in the city of New York, was opened in 1832. These cars, illustrated in fig. 100, were constructed with bodies like those of the road coaches of the time. The car had

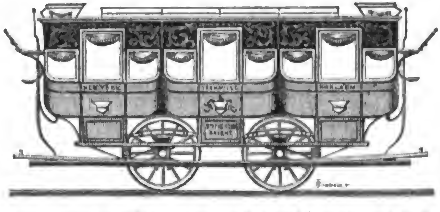


Fig. 100. Original Tram-car, manufactured in 1831, by Mr. John Stephenson, New York.

three compartments, each of which had side doors The body was supported on leather springs. The driver was seated on a dickey, or elevated seat, at the front; the brake, which acted on one pair of wheels only, was moved by the driver's foot. The wheels, brakes, drawheads, &c., were combined in a 'carriage-part,' a structure independent of the body, which rested on the four axle-boxes of the carriage-part. On this principle of arrangement, tramway cars were for several years constructed, until it was found by experience that the portions of the carriage-part not carried by the springs, soon became worn and disordered, and required to be early renewed. One of the first alterations in design, consisted of the substitution of laminated steel springs for the leather springs; the ends of the springs were confined in pockets on the under side of the body, whilst the springs were secured, by the middle, to the axle-box. Then the carriage-part was dispensed with. Pedestals in jaw-plates, known as axle-guards in England, were not used. Though this form of running gear was practised for several years, it was unsatisfactory, because the adjustment of wheels and axles was not positive. Single jaw-plates were then applied to take the axle-boxes and keep the axles square.

About the year 1856, volute steel springs were substituted for laminated side-springs, and were succeeded by 'spiral,' or, properly, helical steel springs. In every case, a single steel spring rested on the top of the axle-box. But, in 1858, a pair of helical springs were provided for each bearing; a yoke was placed on the axle-box, astride, and sustained a spring at each side of the box. About the same time, a method of preparing indiarubber was discovered, by which it preserved its elasticity independently of heat and cold, whilst its power of sustaining loads was greatly increased. The combination of cheapness, durability, and smoothness of action, led to the abandonment of steel bearing springs for those of indiarubber. But, since the expiration of the patent for the method of preparation, the manufacture of the indiarubber springs was thrown open to the public, inferior goods were placed in the market, the good name acquired for indiarubber springs was damaged, and, as a consequence, spiral and other springs came again into demand.

The wheels made for the original American car, fig. 100, were of cast-iron, with flat spokes, as shown. The 'hub,' or nave, was parted radially into three sections, to provide for the shrinking of the metal as it cooled. But the wheel was not strong, and solid wood wheels with iron tyres were substituted. These were heavy and expensive, and they were liable to fail by the loosening of the tyre. About 1834, the cast-iron plate-wheel, or disc-wheel, was introduced; it is regarded in America as the best type of wheel for all kinds of service.

It was for many years supposed that a tram-car ould not stay on the track if the depth of the flanges of the wheels were less than 1¼ inches; and, although a slight reduction was made on the depth, it was not until the year 1857 that it was discovered that a depth of half an inch was sufficient for the purpose. The half-inch flange is now universally employed on tramways.

The brakes, until 1858, consisted of clogs or shoes applied to the treads of the wheels; but when the flat tram-rail, or step-rail, came into use, it was found that, as good car-wheels wear off ½ inch of the thickness at the circumference before being 'used up,' the flange became half an inch deeper, and was made to 'touch bottom,' when, usually at the end of three or four years, the rail was split by the penetrating action of the flange. The additional rubbing resistance, at the same time, arising from the frictional contact of the two surfaces of different radii—the tread and the flange—amounted to from 30 to 50 per cent. of the resistance under normal conditions. But the objections of unequal wear, were met by extending the width of the brake-blocks, so as to confine and take a bearing upon the flange as well as upon the tread of the wheel. The flange was worn down at the same rate as the tread, the life of the wheel was prolonged, the rail was saved from rupture, and the additional resistance to traction was prevented.

The hardest kind of chilled iron is the best material for brake-blocks, for the purpose of wearing upon the flanges of the wheels. But it is not the best for stopping the car, for it does not 'cling' to the wheel so well as softer iron does. Still, the brakes should have a sufficient degree of pressure applied to arrest the turning of the wheels.

In the construction of American cars, the best American white oak is used for the framework of the substructure, and the best white ash for that of the body. The life of a tram-car in America, properly maintained, is from 25 to 30 years. On the New York and Haarlem Tramway, cars placed there in 1857 are still running. Mr. Bancroft states that the wheels last for about 30,000 miles, and the axles for from 200,000 to 300,000 miles. On tramways of from 4 to 8 miles in length, with gradients varying up to 1 in 25, cars taking 80 passengers as a maximum load, are drawn usually by two horses; in very hot weather, a third horse is occasionally attached to assist the others on a steep incline.

The price of 'top-seat' cars in America is about 11,000 dollars, or £229.

Mr. Martineau[1] gives the following table of the capacity the and weight of tramway cars and waggons:—

WEIGHT OF ENGLISH AND FOREIGN CARS, CONSTRUCTED BY THE STARBUCK CAR AND WAGGON COMPANY.

| | Weight<br>cwt. | <br>qrs. | <br>lbs. |
|---|---|---|---|
| CARS:— | | | |
| London car, to seat 22 in and 22 out | 49 | 3 | 0 |
| Hoylake „ 22 „ 24 „ | 46 | 3 | 7 |
| Birkenhead „ 22 „ 24 „ | 47 | 1 | 14 |
| Oporto „ 20 „ 20 „ | 40 | 2 | 0 |
| Middlesbro' „ 16 „ 16 „ | 34 | 0 | 0 |
| Naples, open car, with 5 transverse seats, to seat 20 | 21 | 1 | 20 |
| Naples, car to seat 12 inside only (with partition) | 26 | 3 | 14 |
| Naples, car to seat 16 inside only | 34 | 0 | 0 |
| Brussels „ 16 „ | 34 | 0 | 0 |
| Middlesbro' „ 14 „ | 24 | 1 | 0 |
| Sheffield „ 16 „ | 29 | 0 | 0 |
| Leeds „ 18 „ | 31 | 0 | 0 |
| TRAMWAY GOODS WAGGONS:— | | | |
| Pernambuco waggon | 29 | 2 | 11 |
| Oporto open goods | 27 | 1 | 0 |
| „ covered goods | 32 | 1 | 0 |

*Note.*—The weights above given include wheels and axles.

---

[1] *Proceedings of the Institution of Civil Engineers*, vol. l., page 42.

From this statement, it appears that the weight varies from 2½ tons for a full-sized car carrying forty-six passengers, to 24 cwt. for a light one-horse car carrying fourteen inside. Some heavier cars, not mentioned in the table, have been made for Russia, weighing 3 tons. They were made with wrought-iron underframing, iron panels, and elliptic springs. The bearing-springs of tram-cars are most commonly made, wholly or partly, of indiarubber; but it had been found that they would not bear the extreme and lasting cold of a Russian winter, for which steel springs are indispensable. Steel springs, in connection with screw-brakes, which are preferred by Russian engineers, make the Russian car, of course, a heavier vehicle than English cars.

Light one-horse cars are used in England—principally at Sheffield, Leeds, and Leicester. They are also much used on the Continent—in Naples, Oporto, Antwerp and Brussels—and it appears that they are extending in use, and are replacing the two-horse car with roof-seats, or an 'imperial,' as the upper stage is designated. As Mr. Martineau justly observes, there can be no doubt that the heavy weight of roof-seats, with a number of people on them, strains the framework of a car, in starting and stopping, and that, therefore, cars made without such seats last the longest. It has been said that the essence of a tramway is to keep up a continuous flow of traffic, so that, if possible, a car should always be in sight; and the principle of continuity of service may often be more economically maintained by means of one-horse cars than by heavier cars with two horses.

Taking wide averages, it may be stated that the number of passengers carried per mile run by cars is seven. The signification of this statistical item is, that seven passengers are taken up and set down per mile run by each car. Supposing that a car, going 70 miles in a day, makes four stoppages per mile-run, for passengers and interruptions, it would be stopped and started nearly three hundred times a day. When it is reflected that a 2½-ton car fully loaded with passengers, becomes a moving mass equal to 6 tons in weight;—or, half loaded, upwards of 4 tons;—it is clear that the duty of arresting such a heavy mass, with the resumption of motion, entails a vastly greater internal stress, comparatively, than is borne by ordinary 30-cwt. omnibuses, or even by railway carriages. Railway carriages, themselves, strongly framed though they be, shake loose in the framework. The elastic oscillation of the body framing of these may be observed at the doorways, in many instances, when a train is started, if the valve-gearing of the locomotive be not equally adjusted so as to generate an even pull on the train.

But there is the patent objection to the smaller cars, that what is fictitiously called the 'dead weight' of the smaller car constitutes a larger proportion of the gross weight with passengers, than that of the larger car. It was seen, for example, that the 2½-ton car can carry 3½ tons of passengers—'paying weight'—whereas the 24-cwt. car can take little over a ton of passengers. Otherwise—

| | | | | |
|---|---|---|---|---|
| The 2½-ton car | weighs | 1·08 | cwt. | per passenger. |
| The 24-cwt. | „ | 1·71 | „ | „ |

showing that the lighter car has 57½ per cent. more weight of material per passenger than the heavier car. There is a certain degree of force in the argument thus deducible in favour of the heavier car. But it may mislead. Suppose, on the contrary, that the heavier car conveyed on an average only as many passengers as the lighter car with its load, it might with an equal degree of plausibility be made to appear, that the lighter car would be much the more economical, since there would be a gross weight of 4½ tons against only 3¼ tons for the lighter car. And, again, the lighter car employs only one horse, whilst the heavier employs two.

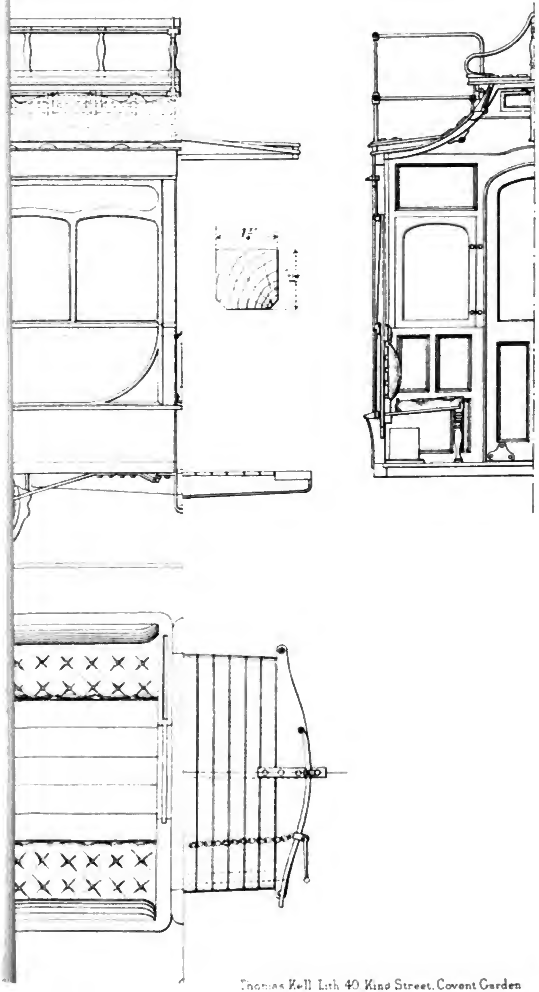
## CHAPTER II.

### INSIDE AND OUTSIDE PASSENGER-CAR, CONSTRUCTED BY THE METROPOLITAN RAILWAY CARRIAGE AND WAGGON COMPANY.

PLATE VII.

THIS car was constructed for the North Dublin Street Tramways. It is suited to the railway and tramway gauge of Ireland—5 feet 3 inches. It seats 20 passengers inside, and 22 outside: total, 42 passengers. The weight of the car is about 2½ tons, equivalent to 1·19 cwt. per passenger. The weight of 42 passengers is 3 tons; and the gross weight, fully loaded, is 5½ tons. The body of the car is 15 feet 3 inches long, and 6 feet 8 inches wide, outside measurement. It is about 10 feet 1 inch high to the roof seats, and the total height over all amounts to 11 feet 3 inches. The total length of the car is 21 feet 3 inches, in which a length of 3 feet is allowed at each end for the platform. The length of the body, inside, is 14 feet 7½ inches, which, for 10 seats on each side, provides an allowance of 17½ inches per passenger. On the roof, the allowance per passenger for 22, or 11 on each side, amounts to about 16½ inches. The wheels are placed at centres 6 feet apart.

**TRAM** Plate VII.



Thomas Kell Lith 40 King Street, Covent Garden

UNIV.

The roof-seats are approached by a spiral staircase at each end. The inside seats are stuffed with the best curled horsehair, and covered with Utrecht velvet. The body is closed by a sliding door at each end. All the side windows, except two on each side, are fixed; these two slide downwards, and they are fitted in the slides with steadying springs. Sliding curtains are mounted on iron rods. Ventilation is provided by means of small hinged windows under the outside seats. Two lamps are fixed within the car.

The whole of the framing is of well-seasoned oak or ash, and the panels are of mahogany, $\frac{3}{8}$ inch thick. The doors are of ash. The roof is covered on the outside with canvas, rendered thoroughly watertight with paint. The canvas is protected by boards or slats, forming footpaths for outside passengers.

The underframe consists of two side-soles, $3\frac{1}{2}$ by 3 inches, two end-soles, $4\frac{1}{2}$ inches wide and 3 inches deep, rebated for the floor-boards, and four cross-bars, $3\frac{1}{2}$ inches wide, and 2 inches deep. The flooring-boards are 1 inch thick, let flush into the side-soles and end-soles. The corner-pillars are $3\frac{3}{4}$ inches by $4\frac{1}{2}$ inches, rounded at the outer angles. There are seven intermediate pillars at each side, between which the side-windows are framed. The upper side-rails are $2\frac{1}{2}$ inches square. The end-rails are $1\frac{1}{2}$ inches thick, shaped to the form of the roof; and there are 16 intermediate roof-sticks, $1\frac{1}{4}$ inches square, placed at distances of 11 inches apart between centres. The roof-boards are $\frac{1}{2}$ inch thick, and the flooring-boards on the roof are $\frac{5}{8}$ inch thick. Each platform is carried by three cantilevers, $2\frac{3}{4}$ inches thick, and

$5\frac{3}{4}$ inches deep at the middle, bolted to the underframe of the car.

The wheels and the axles, figs. 101, 102, 103, are of cast steel. The wheels are 30 inches in diameter, and are each formed with six spokes; one of them is keyed fast on the axle, and the other is loose and revolves independently; it is formed with a nave 8 inches in length, hollow in the middle, making a receptacle for oil. The rim is $2\frac{1}{2}$ inches wide, and is formed with a flange projecting $\frac{9}{16}$ inch from the tread of the wheel, according to the section, fig. 103. The axle is $2\frac{1}{2}$ inches in diameter between the wheels, and $2\frac{3}{8}$ inches in the naves of the wheels. The journals are $1\frac{7}{8}$ inches in diameter, and $4\frac{3}{4}$ inches long. They are formed with flat ends, without collars, and they take their bearings endwise against steel wearing-plates, inserted in the axle-boxes. The diameter of the tread is

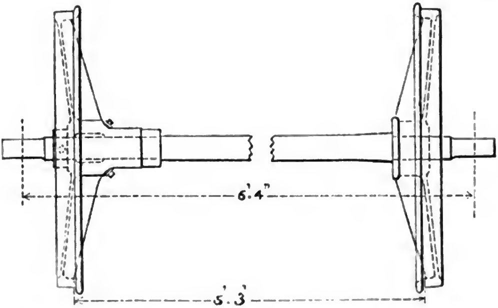


Fig. 101. Dublin Passenger-Car:—Wheels and axle. Scale, $\frac{1}{16}$.

2 feet 6 inches next the flange, and it is $\frac{1}{8}$ inch less at the outer edge, making a slope of $\frac{1}{16}$ inch, or 1 in 24, on the face of the tread. The rim is $\frac{7}{8}$ inch thick at the outer edge. The two wheels are placed on the axle at a distance of 5 feet $1\frac{1}{4}$ inches between the backs of the tyres, which is $1\frac{3}{4}$ inches less than the gauge of the rails; so that, deducting the thickness of the two flanges, $\frac{1}{2}$ inch remains for play. When the wheels, therefore, stand centrally on the rails, the flanges are just $\frac{1}{4}$ inch clear of the rail at each side. This is an important point. It is necessary that the flanges of the wheels should not touch or revolve against the inner ledges of the rails; in order that any binding of the way, and increased resistance, and probable alteration of gauge, or derailment, may be avoided. It is well, therefore, that the clearance between the flanges and the treads of the rails should be limited to what is just requisite for free circulation, and the whole remaining width of the groove given to the inside. There is another advantage in this disposition of the wheels, that detritus collected in the groove is the more easily pushed aside by the action of the flanges. The length of the axle between the centres of the journals is 6 feet 4 inches, being 13 inches larger than the width of gauge. The overhang of $6\frac{1}{2}$ inches at each end—or 5 inches from the nave of the wheel

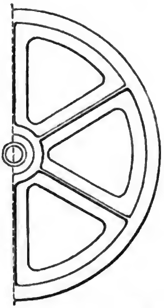


FIG. 102. Dublin Passenger Car:—Side view of wheel. Scale. $\frac{1}{18}$.

—confers the advantage of some degree of elasticity of action, as between the rigid bearing of the wheel on the rail and the bearing of the axle-box.

The axle-boxes, fig. 104, are of American pattern; they are excellently constructed, with lubrication by oil. They are very simple. The body of the box is cast in one piece, with a receptacle in the lower part for cotton-waste, which is soaked with oil, and laps the journal below. The brass or gun-metal bearing, fig. 105, is formed with a hollow in the upper side, as a receptacle for oil, which is introduced through a hole in the top of the box, and is admitted upon the journal through two oil-holes in the brass. The

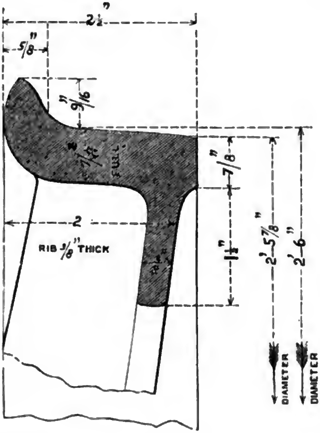


Fig. 103. Dublin Passenger Car:—Section of rim of wheel. Scale, ½.

brass bears upon the journal for all its length, but is restricted to a narrow width of contact, about $1\frac{3}{16}$ inches, upon the journal: being five-eighths of the diameter. The horizontal area of the bearing-surface on one journal is ($4\frac{3}{4} \times 1\frac{3}{16} =$) 5·64 square inches, upon which the maximum load is a fourth of, say, 5 tons, or 2,800 pounds—equivalent to 500 pounds on the square inch of bearing-surface. Again, for the horizontal area of the journal, which amounts to ($4\frac{3}{4} \times 1\frac{7}{8} =$) 8·41 square inches, the maximum load is equivalent to 333 pounds per square inch. These are great amounts of pressure concentrated on a square inch of surface. They may be contrasted with the corresponding distribution of pressure on the axle-journals of railway rolling stock:—

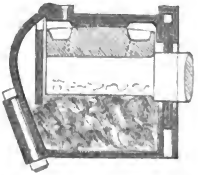


FIG. 104. Dublin Tram-car:—Axle-box. Scale, $\frac{1}{8}$.

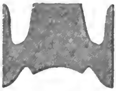


FIG. 105. Dublin Tram-car:—Section of brass bearing in axle-box. Scale, $\frac{1}{4}$.

| | Tramway car lbs. | Railway stock lbs. |
|---|---|---|
| Load per square inch of bearing surface . | 500 ... | 300 |
| Do. do of horizontal area of journal . . . . . . | 333 ... | 224 |

The excess of pressure in tramway cars is warranted by the limited speed of tramway traffic, with the frequency of stoppages. But there is another feature in this axle-box, of great utility—the grit-shield, made of papier-maché, which embraces the axle, and is let into a groove formed in the back of the axle-box. The shield not only excludes dust and dirt from the axle-box, but it also aids in preventing waste of oil.

The brass is free to slide laterally under the upper part of the axle-box, and is slightly rounded at the surface of bearing on the box. The needful end-resistance is supplied by the steel bearing-plate, already noticed, let into and sustained in vertical grooves in the front part of the box, to oppose the end of the journal, and limit the lateral play of the axle in the axle-boxes to an allowance of $\frac{3}{8}$ or $\frac{1}{2}$ inch. The journal is also free to slide laterally, to a limited extent, under the brass. The effect of all this freedom of action is, that the liability to binding or heating in the axle-boxes is reduced to a minimum, whilst the traction of the car is facilitated.

A portion of the front of the axle-box is readily removable, so that every part of the axle-box may be opened to inspection, and the brass withdrawn, or the stuffing renewed. The axle-box, as a whole, may also be withdrawn from the axle.

The axle-guards are of cast-iron, bolted to the side-soles. They are formed with broad bearing-surfaces, to support the axle-box for its whole length, from front to back, and with a recess at each side of the axle-box, in which the bearing-springs are lodged. The springs are of indiarubber, two to each axle-box; they are manufactured by the North British Rubber Company. They are barrel-shaped, and placed on end, each of them between two dished washers, upon the lateral extensions of a wrought-iron saddle, which bestrides the axle-box. The side-soles of the car take a bearing upon the upper ends of the springs.

The bearing-springs are formed of a special compound of indiarubber, stiffer than pure rubber, so as to dispense with the aid of steel as an auxiliary. There is no need for steel in combination with rubber anywhere, provided that a sufficient area of base is obtained for the rubber. There is a pair of indiarubber springs over each axle-box, which are about 7 inches high, when unloaded, and $4\frac{1}{2}$ inches in diameter at the middle. They are reduced in height $\frac{3}{8}$ inch by compression under the empty car, under a net weight of, say, 2 tons. Divided over eight springs, the compressing weight per spring is $\frac{1}{4}$ ton—whence it is deduced that the springs yield at the rate of $(\frac{3}{8} \times 4 =)$ $1\frac{1}{2}$ inches per ton on each spring, in the first stages of compression. Under the net load of 5 tons, the load per spring would be $(5 \div 8 =)$ $\frac{5}{8}$ ton, and the total deflection would be $(1\frac{1}{2} \times \frac{5}{8} =)$ nearly 1 inch for each spring.

The brake, on the system known as Stephenson's, of New York, is worked from the platform at each end of the car. A block of cast-iron is applied to each wheel. The blocks are hung as two pairs, each pair on a transverse swing-beam, applicable to one pair of wheels. The beams, when not under pressure, hang free of the wheels. The power is applied by hand by turning a vertical iron shaft or spindle, on which a chain is coiled. The chain is connected to one end of a long intermediate transverse lever, pivoted under the centre of the car, from which, by pulling-rods pinned to it near the centre, the swing-beams and brake-blocks are pulled into contact with the wheels. The actual pressure applied to the wheels in this manner may be calculated from the dimensions of the brake-gear. The handle, or crank, has a radius of 10 inches, whilst the chain is coiled on the shaft to a mean radius of about ⅞ inch. Next, the chain pulls the intermediate lever at a radius of 22½ inches, measured from the central pivot, and the pulling-rods are connected at a radius of 4½ inches. Applying these data, the pressure applied at the handle is multiplied or intensified 72 times when it is transmitted to and applied to the wheels: calculated thus, in terms of the ratios:—

| Ratio of | Inches | | Inches |
|---|---|---|---|
| Handle to chain . . . . . . | 10 | to | ⅞ |
| Long lever to short lever . . . | 22½ | to | 4½ |
| Final ratio . . . . | 225 | to | 3·94 |
| or, Leverage of the power . . | 57 | to | 1 |

Suppose that a man can apply, on an emergency, a pressure of 56 lbs. to a crank-handle. The statical equivalent of this pressure at the handle is (57 × 56 =) 3,192 lbs. at the tyres of the wheels, or 1·42 tons. This is the breaking force that may be applied to the wheels; and, supposing that the coefficient of frictional resistance between the brake-blocks and the wheels is the same as that between the rails and the wheels, it would appear that the wheels may not be skidded by the application of this brake, even when the car is empty, when the weight is 2½ tons. Of course, with its complement of weight, as passengers, adding a ton and a half, and making up 3 tons gross, it is still less practicable to skid the wheels, unless the coefficient of friction of the brake-blocks is considerably greater than that upon the rails. In practice, the wheels can be skidded by the brake.

Framework of such slender scantling as that of the tramway car, with a contracted wheel-base, great overhang, and seat-room for a heavy load of passengers, it is needful to stiffen by means of truss-rods. The underframe is strengthened by a trussing of iron bars applied under the seats, with tightening screws at the ends, under the side-soles; and by tie-bars and diagonal rods connecting the axle-guards and the side-soles. The roof, too, being of the form of an interrupted arch, to make a support for the roof-seats, requires to be trussed; and in order to stiffen the roof, a segmental truss-rod is applied at each side, suspended between the ends of the body, and clasped to the roof-ribs.

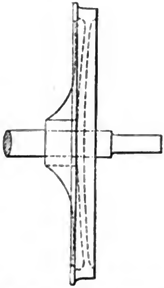


FIG. 106. Disc car-wheel and axle. Scale, $\frac{1}{16}$.

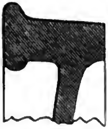
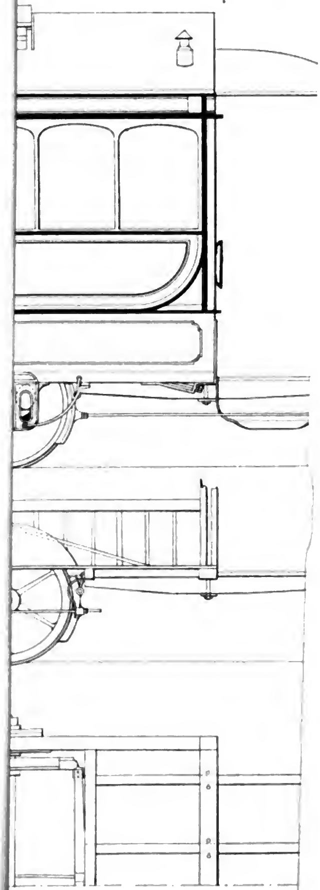


FIG. 107. Disc car-wheel. Section of tyre. Scale, $\frac{1}{4}$.

The price of this car, to the Irish gauge, is £194, at the works; to the English gauge, the price of the car, of equal capacity, is £192. 10*s*. The weight in each case is taken at 2½ tons.

The ordinary solid disc-wheels and axles employed by the Metropolitan Company for tram-cars, are shown in figs. 106, 107. The wheels are dished inwardly, with stiffening flanges on the back; they are 30 inches in diameter. The naves are 4½ inches deep, and are simply driven tightly upon the axle, where they remain without the aid of keys. The disc is ⅞ inch thick at the nave, and is reduced to a thickness of ⅝ inch at the rim. The rim is 2¾ inches broad, comprising the thickness of the flange, ½ inch, and the width of the tread, 2¼ inches. The flange projects ½ inch from the tread; the axle is 3 inches in diameter between the wheels, 2⅞ inches in the naves; and the journals are 2 inches in diameter, by 5½ inches long.

BY THE STARBUCK CAR CO



SCALE $\frac{1}{36}$th FULL SIZE.

# CHAPTER III.

## INSIDE PASSENGER-CAR, CONSTRUCTED BY THE STARBUCK CAR AND WAGGON COMPANY.

### PLATE VIII.

THE passenger-car, to hold 18 passengers inside, illustrated by Plate VIII., is an excellent example of its kind. The body is 14 feet long, and 6 feet 7 inches wide, outside measure. The clear length inside is about 13 feet 3 inches, which, for 9 persons on each side, contains an allowance of $17\frac{2}{3}$ inches for each passenger. This allowance is liberal: in omnibuses, 16 inches only is allowed. The weight of the car is 31 cwt.; equivalent to 1·72 cwt. per passenger. The total length of the car, over the platforms, allowing

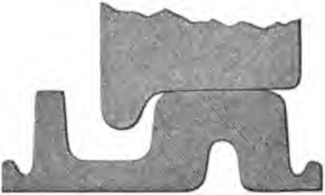


FIG. 108. Section of wheel-tyre of the Starbuck car. Scale, ½.

3 feet for each platform, is 20 feet; and the extreme height, above the rails, is 9 feet 3 inches. The gauge of the rails is 4 feet 8½ inches.

The wheels are 2 feet 6 inches in diameter, of cast iron chilled at the tread and the flange, which are of the section shown in fig. 108; the axles are 3 inches in diameter, and are of best scrap iron. They are placed at a distance of 5 feet 6 inches between centres. The bearing-springs are of indiarubber—two blocks to each axle-bearing. The brake is of the same design as that already described for the Dublin car; but the proportions are different, thus:—

| Ratio of | Inches | | Inches |
|---|---|---|---|
| Handle to chain . . . . . . | 9 | to | 1 |
| Long lever to short lever . . . | 24 | to | 3 |
| Final ratio . . . . | 216 | to | 3 |
| or, Leverage of the power . . | 72 | to | 1 |

For a pressure of 56 lbs. at the handle, the statical equivalent at the wheels is (72 × 56 =) 4,032 lbs., or nearly 2 tons—a considerable greater pressure, for a considerably lighter vehicle, than was found for the Dublin car. In short, the leverages are respectively as follows:—

| Car | Total weight half-loaded | Leverage of brake | Leverage per ton of weight |
|---|---|---|---|
| Metropolitan . | 4¼ tons ... | 57 to 1 ... | 13·4 to 1 |
| Starbuck . . | 3 „ ... | 72 to 1 ... | 24 to 1 |

Such variations of practice point to the greater strength and power of resistance to braking stress of the solid-roofed cars, relative to cars with interrupted roofs and top loads.

# CHAPTER IV.

## RADIAL-AXLE PASSENGER-CAR, BY MR. JAMES CLEMINSON.

For tramways, quite as much as for railways, the radiating axle is necessary for facilitating the passage of cars on curved portions of the way, and reducing the tractional resistance. Mr. Cleminson's system of three axles, forming a self-adjusting or 'flexible' wheel-base, complies with the conditions of the problem in a satisfactory manner. The axles, with their axle-boxes, springs, and guards, are mounted in independent frames, one to each axle, separate from the main underframe of the carriage. The end frames are fitted with central pivots, on which they swivel freely, whilst the middle frame is so arranged that it can slide transversely. The three frames are connected together by articulated radiating gear, so that they act sympathetically, in such a manner that when the carriage or the car, leaving a straight portion of the way, passes on to a curve, the end axles are deflected horizontally, forming angles with the central axle, and taking up radial positions coincident with the radii of the curve. By means of such self-acting adjustment, the car rolls freely round the curve. When, conversely, the car passes from the curve to the straight line, the axles

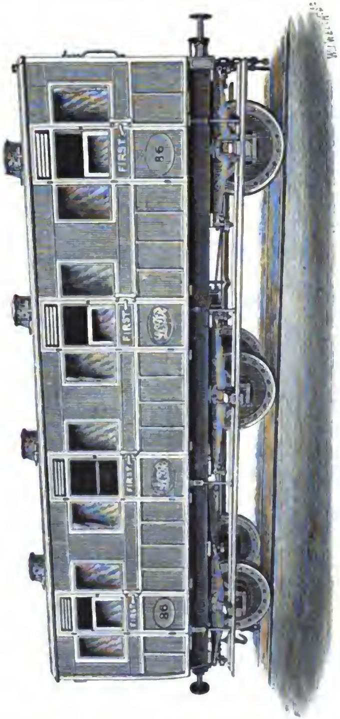


Fig. 109. Railway Carriage, fitted with Mr. Cleminson's system of radiating axles.

resume their parallelism, and the car rolls on naturally in a straight line. The automatic action arises from the translation of the middle axle and frame transversely, on a curve: the relative lateral

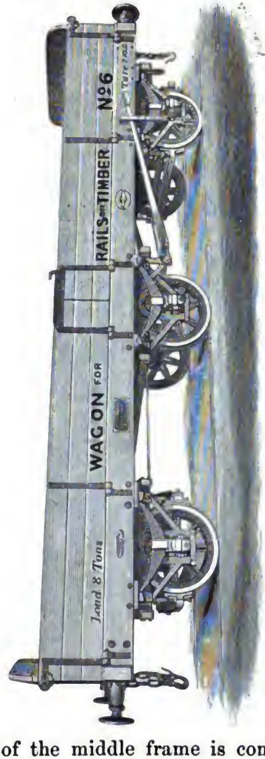


Fig. 110. Railway Waggon, fitted with Mr. Cleminson's system of radiating axles.

movement of the middle frame is communicated to the near sides of the end frames, causing them to swivel on their pivots, and to turn the end axles into appropriate radial positions.

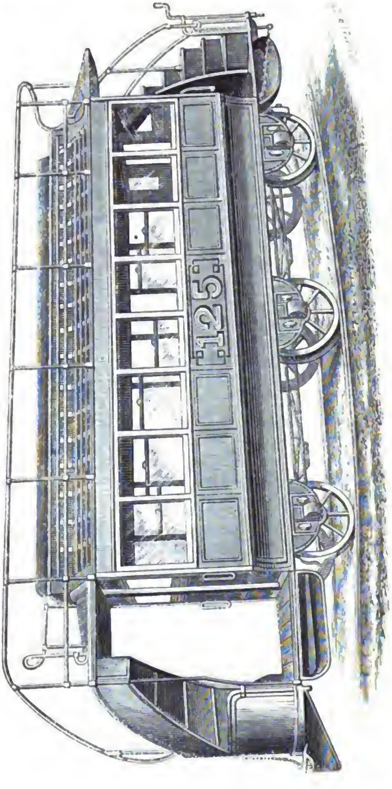


Fig. 111. Tram-car, fitted with Mr. Cleminson's system of radiating axles.

Mr. Cleminson's experience with his system of the 'flexible wheel-base' has hitherto been derived, for the most part, from railway rolling stock. Some first-class carriages constructed on this system by the London, Chatham, and Dover Railway Company, fig. 109, have been at work for some time. One of them, it is reported, after having run 30,000 miles, has not shown any sensible wear of the wheel-flanges, whilst the flanges of ordinary carriages on the same line are worn to a thin edge with half that mileage. Several railway waggons, fig. 110, have been constructed on the same principle. The system lends itself freely to the extension of the length and capacity. The waggon, here illustrated, has the capacity of two ordinary waggons; whilst the weight is 20 per cent. less.

Mr. Cleminson's radial-axle tram-car, fig. 111, is at work on the Dublin and other tramways. The wheels are placed widely apart under the body of the car, and the pitching movement incidental to the working of tram-cars constructed with the ordinary contracted wheel-base, is extinguished. This car seats 18 passengers inside, and 22 outside; total number, 38. The weight of the car is 45 cwt., equivalent to 1·18 cwt. per passenger.

# CHAPTER V.

## BEARING SPRINGS.

THE calculations for the depression of side-springs, at page 289, are but roughly approximate, for the rate of compression or deflection of such springs diminishes as the load is increased. For instance, for the barrel-shaped indiarubber springs manufactured by Messrs. George Spencer & Co., for tramway cars—7 inches high, $4\frac{3}{8}$ inches in diameter at the middle, and $2\frac{7}{8}$ inches in diameter at the ends—the deflections, or reductions of height, for given vertical loads are as follows :—

MESSRS. GEORGE SPENCER & CO.'S INDIARUBBER SPRINGS.

| Load | Total height | Maximum diameter | Deflection, or reduction of height |
|---|---|---|---|
| Tons | Inches | Inches | Inches |
| 0 | 7 | $4\frac{3}{8}$ | 0 |
| $\frac{1}{2}$ | $5\frac{3}{16}$ | $4\frac{3}{4}$ | $1\frac{13}{16}$ |
| 1 | $4\frac{1}{16}$ | $5\frac{1}{4}$ | $2\frac{15}{16}$ |
| $1\frac{1}{2}$ | $3\frac{5}{8}$ | $5\frac{1}{2}$ | $3\frac{3}{8}$ |
| 2 | $3\frac{1}{4}$ | — | $8\frac{3}{4}$ |

For a similar spring, of the same manufacture, 7 inches high, $5\frac{7}{16}$ inches in diameter at the middle, and 3⅛ inches in diameter at the ends, the deflections were as follows:—

| Load | Total height | Maximum diameter | Deflection, or reduction of height |
|---|---|---|---|
| Tons | Inches | Inches | Inches |
| 0 | 7 | 5 7/16 | 0 |
| ½ | 5½ | 5⅞ | 1½ |
| 1 | 4¾ | — | 2¼ |
| 1½ | 4 3/16 | 6⅝ | 2 13/16 |
| 2 | 3 13/16 | 6⅞ | 3 3/16 |

The deflections in the last columns increased less rapidly than the loads, insomuch that the rates of deflection per ton of load, under increasing loads, were as follows:—

| Load | Deflection per ton of load | |
|---|---|---|
| | 1st spring | 2nd spring |
| | Inches | Inches |
| 0 | — | — |
| ½ | 3⅝ | 3 |
| 1 | 2 15/16 | 2¼ |
| 1½ | 2¼ | 1⅞ |
| 2 | 1⅞ | 1⅝ |

Under a load of 5¼ tons net, eight of these springs would have each to support ⅔ ton, corresponding to an elasticity measured by about 3⅜ inches per ton for the first spring, and about 2¾ inches per ton for the second spring. These deflections are much greater than those of the North British Rubber Company, page 289.

It appears from the results of the deflections of Mr. Spencer's springs that the elasticity under a load of 2 tons is only about half of the elasticity under a load not exceeding half a ton. Also that the deflection is inversely as the cube-root of the quantity of material in the springs. For, the diameters of the springs are respectively $4\frac{3}{8}$ inches and $5\frac{7}{16}$ inches, of which the squares are as 2 to 3, and are as the quantities of matter in the springs. Now, the deflections under 2 tons of load, are $1\frac{7}{8}$ inches, and $1\frac{5}{8}$ inches, and $\frac{15}{8} : \frac{13}{8} :: \sqrt[3]{3} : \sqrt[3]{2} :: 1{\cdot}44 : 1{\cdot}26$, or as 15 to 13. That is to say, the cube-roots of 2 and 3 inversely are as $1\frac{7}{8}$ to $1\frac{5}{8}$.

Further, as the quantities of material in the springs—being of the same height—are as the squares of the diameters, the deflections are inversely as the cube-roots of the squares of the diameters, or as the $\frac{2}{3}$ power of the diameter.

The quality of the indiarubber spring, whereby the resistance to compression increases more rapidly than the load, is in ordinary conditions objectionable; for it momentarily intensifies the resisting stress opposed to oscillations of the car fore and aft. It contrasts in this respect disadvantageously with the ordinary laminated spring, of which the increase of deflection is uniform for equal additions of load. But, under the actual conditions of a tram-car, placed on axles which are near together, with considerable overhanging masses at each end, the increasing rigidity of the springs under increasing pressure, has a powerful influence to check the fore-and-aft oscillation of the car, and to reduce the extent of the oscillation.

The 'rubber-centre spiral springs,' manufactured by Messrs. L. Sterne & Co., offer a compromise between the uniform increase and the accelerated increase of resistance to increase of load. A pair of their springs of the C pattern, suitable for tramway stock, is deflected 1·47 inches under a load of 1·785 tons, equivalent to ·86 inch per ton. The annexed table of deflections and loads, based on the results of experiments made by Mr. Kirkaldy, exemplify the compromise referred to, showing that the increase of rigidity is much less than that of springs made entirely of indiarubber. Each spring consists of a central core of indiarubber, 2 inches in diameter, within a helical steel spring, 3 inches in diameter outside, of $\frac{9}{16}$-inch round steel, made in 8½ complete coils, to a length of 8 inches:—

| Compression or deflection | Load | Total deflection per ton of load |
|---|---|---|
| Inches | Tons | Inches |
| ·45 | ·446 | 1·00 |
| ·81 | ·892 | ·91 |
| 1·16 | 1·339 | ·87 |
| 1·47 | 1·785 | ·82 |
| 1·73 | 2·232 | ·77 |
| 1·89 | 2·678 | ·71 |
| 2·04 | 3·124 | ·65 |

It may be remarked that though the stiffness of the Sterne spring increases less rapidly than that of the Spencer spring, the Sterne spring is on the whole much stiffer than the Spencer spring.

# CHAPTER VI.

## CAR-WHEELS.

CAST-IRON wheels, chilled at the periphery, manufactured in America, are used for tramway-cars. A quality of charcoal iron is secured which admits of crystallisation and chill going to a remarkable distance into the grain of the iron, and a careful system of annealing is adopted for the wheels after they are cast. On tramways in London, car-wheels last fourteen months, performing, say, from 22,000 to 25,000 miles-run. They weigh, when new, about 214 pounds, and they lose in weight from 14 to 16 pounds by wear—chiefly by the action of the brake. They fail by the breaking-off of the flanges.

The Handyside-wheel, fig. 112, which has been successfully employed on railway rolling stock, is well adapted for tramway stock. It is made in three parts—the tyre, the nave, or boss, and a pair of discs uniting the nave and the tyre. The tyre is of steel, or of chilled cast-iron; the nave is of wrought-iron, or of steel, with four radial arms. The discs are of cast-steel, and are dished and turned inwards at the inner and outer circumferences. When put together, the edges of the discs embrace the tyre and the nave by corresponding flanges or lips, whilst at the middle, or half-radius of the discs, they close upon, but do not touch, the ends of the four arms. The discs are bolted together between two ring-washers at the bottom of the hollow, equally all round the nave; and as they do not touch each other, they are placed in a condition of elastic tension, at the same time that they firmly hold the tyre and the nave in position. The wheel has been well tested on the Caledonian Railway, and has given satisfactory evidence of its firmness and durability.

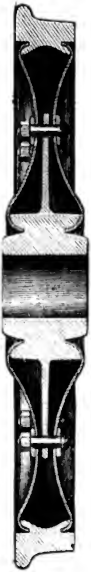


Fig. 112. The Handyside car-wheel.

Mr. C. L. Light makes a wheel, consisting of a cast-iron nave and disc in one piece, with a steel or an iron tyre. The disc is formed with corrugations, which are radial, and, at the same time, have a lateral twist in the plane of the wheel, by which they become slightly serpentine. The corrugations land upon the rim with a sinuous contour, and so afford a continuous, though sinuous, bearing for the rim. The wheel is, by its form, elastic and yet strong.

# CHAPTER VII.

## FRENCH TRAM-CARS.

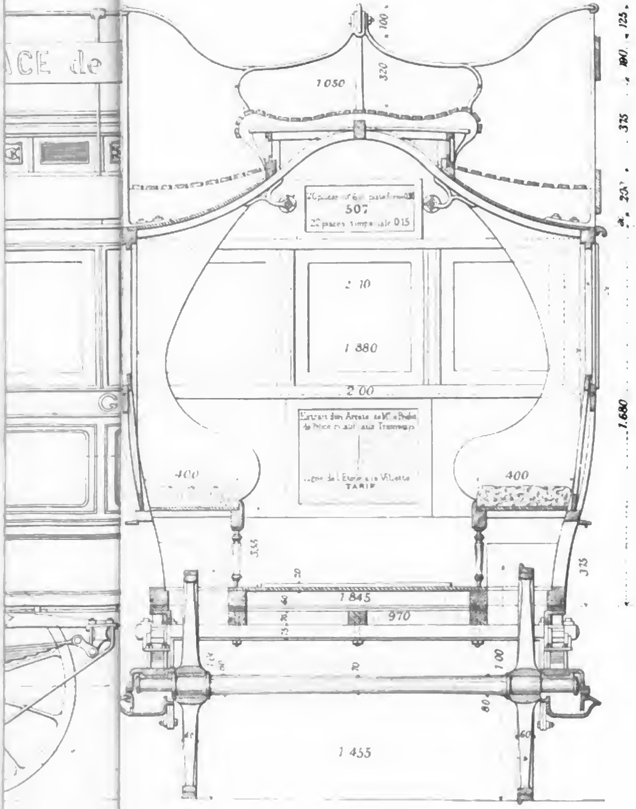
### PLATE IX.

THE *winter car*, designed and constructed by M. Léon Francq, for the tramways from the Arc de Triomphe to the Porte Maillot, accommodates 14 passengers inside, and 7 standing on each platform; total number, 28. The weight of the car, empty, is 1·57 tons; with passengers, 3·36 tons.

| | Feet | Inche |
|---|---|---|
| Total length, extreme | 19 | 0 |
| Length of the body | 11 | 9½ |
| Length of each platform | 3 | 7¼ |
| Length inside | 11 | 5¼ |
| Space per passenger, width | 1 | 7½ |
| Width, transversely, of seats | 1 | 5 |
| Height of seats | 1 | 7¼ |
| Width of passage-way, between seats | 2 | 9½ |
| Width of body, outside | 6 | 7 |
| Width of doors | 1 | 11½ |
| Height of doors | 5 | 11 |
| Maximum height, inside | 6 | 9½ |
| Diameter of wheels (four) | 2 | 4 |
| Distance apart of axles, between centres | 5 | 3 |

With dimensions so spacious, this car only weighs 1·12 cwt. per passenger, or about 4 per cent. more than the inside-and-outside car, described at page 283.

Plate IX



SCA

Thomas Kell Lith 40, King Street Covent Garden

The body is constructed as ordinary coach-work, with cross-bars of double T iron. The panels and the fences of the platforms are of sheet-iron, varnished. The springs were originally constructed on the Belleville system, consisting of dished steel plates, piled on a spindle; but they have been replaced by ordinary springs of indiarubber, barrel-shaped, like those already described, standing 8 inches high, and 4 inches in diameter at the middle. The brake is on Stephenson's system, applied to all the wheels. The price of the car delivered was £180.

The resistance of the car to traction, on a level, varies from 13 lbs. to 22 lbs. per ton, according to the state of the way, at a speed of 7½ or 8 miles per hour.

The *summer car*, designed by M. Francq, has nearly the same leading dimensions as those of the winter car, and accommodates the same number of passengers inside and on the platforms. The sides and the ends of the body are open above the seats, but they are provided with curtains. The weight of the car, empty, is 1·37 tons, equivalent to 1 cwt. per passenger. The price of the car delivered was £160.

The Compagnie Générale des Omnibus use large omnibuses, Plate IX., for inside and outside passengers, on the outer boulevards, on the line between the Etoile and La Villette. There are seats for 20 passengers inside, and 22 outside, and standing room on the platform for 6 passengers; in all, 48 passengers. The body is 16 feet 5 inches long outside; the platform at the back projects 4 feet 10 inches beyond the body; the steps project 7 inches further back; whilst the driver's seat in front projects 3 feet in advance. The total length of the vehicle is 24 feet 10 inches. The width of seat-space allowed in the interior is 19 inches per passenger; on the roof it is 17⅜ inches. The width of the body is 6 feet 7 inches outside. There is one staircase, at the end, leading to the roof, and the steps off the platform descend endwise. The body of the car is supported on transverse framing of wood, mounted on four wheels, 3 feet 3⅜ inches in diameter, at a distance apart of 7 feet 10½ inches. The wheels on one side of the car only are flanged, and are keyed on their axles; those on the other side are made with flat tyres, and are loose on their axles. The fore-wheels only are flanged; those on the other side are made with flat tyres. The fore-wheels run in a movable frame, to which trams for two horses are attached, and which turns on a perch-bolt, and admits of an easy passage on curves. The car rests on laminated springs, having a span of 39 inches. A brake, which can be turned by the driver, may be applied to the hind-wheels of the car. The cars run lightly, and the resistance to traction is much less than that of ordinary tram-cars. The weight of the car empty is 2·95 tons, equivalent to 1·23 cwt. per passenger. The weight, when loaded, is from 6 to 6½ tons. The cost of the car, constructed at the works of the company, is £260.

The cars of the North Company are only seated for inside passengers; 16 inside, with standing room for 16 on the two platforms; in all, 32. The weight is 1⅝ tons empty, equivalent to 1 cwt. per passenger; the weight loaded is from 4½ to 4¾ tons.

The cars of the South Company are seated for 16 inside, 12 on the platforms, and 18 outside; in all, 46. The weight is 2·20 tons empty, equivalent to ·96 cwt. per passenger; loaded, the weight is from 5 to 5·20 tons.

Each car is worked with 8, 10, or 12 horses; each pair making a journey of 10 miles per day. The cars run from 53 to 56 miles per day.

# CHAPTER VIII.

## EADE'S REVERSIBLE CAR.

EADE'S CAR, patented in 1877, has recently (October 1877) been started on the Salford Tramways by the Manchester Carriage Company. The principal object in the design of this car has been to obviate the necessity for unfastening and carrying the draw-bar and pole from one end of the car to the other end, at the terminus;—a duty which is performed by a staff of men known as pole-shifters. The body of the car is swivelled centrally on the underframe, and can be turned round whilst the horses remain in harness, and the driver retains his seat. The body is secured in position by a simple locking apparatus. There is but one entrance to the car, at one end, and two staircases to the roof, one at each side of the entrance. The entrance is reached by three steps, one more step than there are in ordinary cars, as the body is more elevated than is usual. The windows are at a higher level than is usual, and they are considered to be safer. The driver occupies an elevated seat in front.

The body is seated for 16 inside passengers, and 18 outside passengers; in all, 34 passengers.

The body is 12 feet long, and 6½ feet wide, outside measure. It is 11½ feet long inside, giving 17¼ inches per seat. The seat-room outside is 12 feet long, and, for 18 passengers, is equivalent to 16 inches per passenger. The total length, from the front of the dash-board to the end of the staircase, is 17 feet 6 inches. There are four 30-inch wheels to the car, constructed with cast-iron nave, wood spokes and rim, and a flanged steel tyre. One wheel on each axle runs loose, and it is said that the traction is sensibly eased by the additional freedom of movement thus secured. The side-springs are ordinary laminated steel springs as used in omnibuses. A brake-block is provided for each wheel, constructed of wood, secured by four 1-inch iron bolts, which take a bearing with the wood on the wheel. This construction of wood and iron, it is stated, bites more keenly than either wood or iron alone.

The weight of the car, empty, is 34 cwt., equivalent, for 34 passengers, to 1 cwt. per passenger. So low a ratio as this has not been attained in any other English car of the same capacity. The comparative lightness of the car is attained by employing framework of light scantling, wheels of wood, and smaller axles.

It is reported that there is, by the use of the reversible car, a saving of over 30 per cent. in horse-power; inasmuch as the car can be worked with a stud of 8 horses, as efficiently as the ordinary car with 12 horses. Additional cars on the same design are being constructed for the service.

# PART V.

## *MECHANICAL POWER ON TRAMWAYS.*

---

## CHAPTER I.

### HISTORICAL SKETCH OF THE APPLICATION OF MECHANICAL POWER ON TRAMWAYS.

---

LATTA.—GRICE & LONG.—TRAIN.

THE first application of steam for propelling tramway-cars, according to Mr. Cramp,[1] appears to have been made on the Cincinnati Tramway, in 1859, by Mr. A. B. Latta, who constructed a steam-car in which, it is said, eighty persons had been conveyed. The second application was made by Messrs. Grice & Long, of Philadelphia, who constructed a long car on two four-wheel trucks—one under each end of the car. To one of the trucks steam-power was applied by means of toothed gear. In 1860, five or six steam-cars were in use in the United States, in which the engine and boiler were placed within the car, the whole being carried on two bogie trucks. Mr. G. F. Train, in 1860, patented a steam-car, on a Bissell-truck at one end, and a pair of wheels at the other end, driven by a double-cylinder steam-engine with a vertical boiler, with intervening spur-gearing.

---

[1] 'Tramway Rolling Stock,' by Mr. C. C. Cramp: *Transactions of the Society of Engineers*, 1874, page 124.

### Todd.

Mr. Leonard J. Todd, of Leith, it appears, was the first steam-locomotist who, in 1871, designed an engine for tramways, specially adapted for passing through common roads and streets, avoiding noise, smoke, and steam, and possessing great facilities for starting and for stopping quickly. He insisted on the advantage of accumulating power, for which purpose he used a boiler of great capacity, holding a large quantity of water, with a very small fire-grate. 'In the case of a small generator,' he says,[1] 'the only reliable way of making a furnace-boiler which can take care of itself for a considerable time is simply to give it a greater water-capacity and water-area. This water, in the most perfect and natural manner possible, acts the part of a heat-accumulator, as, during a long time, it goes on storing up heat within itself, and but very slowly raising the pressure-gauge; and, again, during a lengthened period it gives off heat from its store, while yet only slowly reducing the pressure and the water-level. Now, this invaluable action of water within a boiler is not carried to any great extent in ordinary locomotives, as there is, in them, no particular use for it, although, on undulating lines, it is well known to be of great importance that a boiler should contain a large amount of water. Now, locomotive boilers contain 5 cubic feet of water, and 3 square feet of water-area for each square foot of grate, and never require attention oftener than, nor, indeed, so often as, every ten minutes. It is evident, then, that if we give six times as much water-capacity and water-area, while still keeping the same size of grate, as far as safety goes, we need only attend to the boiler once in sixty, instead of ten, minutes.' . . . 'The power required to propel a forty-four-seat car, including the weight of the propelling mechanism, with this large quantity of water, will not, on level lines, exceed ten indicator horse-power, although more than this will be required to work heavy roads. Then, small boilers and engines will give ten horse-power for each foot of grate; but we had better allow the grate of the car boiler to contain 1½ square feet; and with 30 cubic feet of water and 18 square feet of water-area—both six times the ordinary locomotive allowance—we get 45 cubic feet as the water-capacity, and 27 square feet as the area at the water-level. The furnace should be of considerable depth, not less than 2 feet below the fire-doorway; so that, before commencing a run, it could be filled with fuel, and then left to sink down as it burns away.'

---

[1] *The Engineer*, July 24, 1874; page 66.

Mr. Todd constructed a steam-locomotive capable of drawing two passenger-cars, with a total of 76 seats, for the Tram Viâ de Santander, shown in fig. 113. The boiler was of the locomotive form, having 3½ square feet of area of grate, and 160 square feet of heating surface. The cylinders were 6½ inches in diameter, with a stroke of 9 inches, and made 150 revolutions of the crank-shaft when the speed was 10 miles per hour. The driving wheels were 5 feet

6 inches in diameter, formed with a disc of wood. There was a bogie-truck in front, having 21-inch wheels at 3 feet between the axles. The fixed wheel-base, between the driving-axle and the centre of the truck, was 5 feet 3 inches. The motion of the crank-shaft was communicated to the driving-wheels by a pair of spur-wheels. The draft of air to the furnace was supplied from a 12-inch fan, driven by the exhaust steam of the engine, which struck the buckets of a bucket-wheel on the axle of the fan. The steam passed thence into the water tank, where water might be deposited, whilst the uncondensed steam escaped into the chimney. With a pressure of steam in the boiler of 150 lbs. per square inch, the engine could exert 20 effective horse-power. The weight in working order was 5 tons. The extreme length was 14 feet 10 inches, and the width over all was 6 feet 6 inches. The chimney was 14 feet 5 inches high above the rails, to clear the awning above the cars.

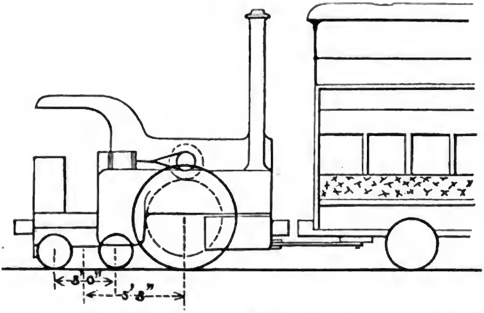


FIG. 113. Steam-locomotive, by Mr. L. J. Todd, 1871. Scale, $\frac{1'}{96}$.

### LAMM.

Dr. Emile Lamm experimented for some time, in 1871, with an ammoniacal-gas car, fig. 114, in New Orleans. He placed a reservoir of hot water on the roof of the car, containing an interior reservoir of liquid ammoniacal gas, produced by heating sal-ammoniac in the presence of a hydrate of lime. The gas was disengaged under the influence of the heat of the surrounding water, and it passed to the cylinders, which were placed vertically at the end of the car, and were connected to a crank-shaft below, from a chain-pulley on which revolving motion was communicated by a corresponding pulley to one of the axles of the car. The gas was exhausted into the reservoir of water, where it was condensed, and its heat was imparted to the water. This process of evolution and condensation was continued until the pressure of the gas in the interior reservoir became

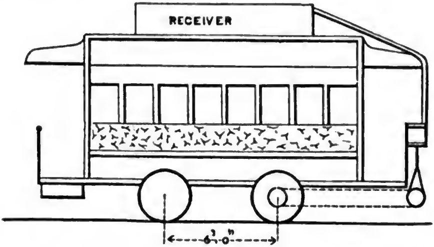


FIG. 114. Ammoniacal-gas Car, by Dr. Lamm, 1871. Scale, about $\frac{1}{96}$.

insufficient for keeping the pistons in motion. The greatest fall of pressure in the gas-generator during a run of seven miles, did not exceed 10 lbs. per square inch. When the water became saturated with gas, it was replaced, and the gas absorbed could be extracted from the water for further service. The greatest difficulty in the employment of ammoniacal gas is the necessity for entirely preventing its escape into the atmosphere, to obviate the offensive smell, and the difficulty of respiration caused by its presence in the air. This objection, together with that of the chemical action of the gas on iron, led to the abandonment of the system of propulsion by ammoniacal gas, though Dr. Lamm's car was at work for some time.

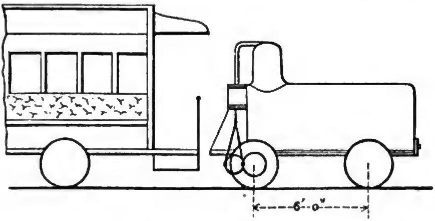


FIG. 115. Hot-water Locomotive, by Dr. Lamm, 1872. Scale, about $\frac{1}{80}$.

Dr. Lamm subsequently, in 1872, started a 'fireless' or hot-water locomotive—a 'thermo-specific engine'—on the line of tramway between New Orleans and Carrolton. The locomotive, fig. 115, consisted of a reservoir, about 3 feet in diameter, and 10 feet long, on four wheels, filled with water heated to a high temperature, under a corresponding high pressure. When the regulator was opened, the pressure was relieved, and steam was formed spontaneously from the water to keep up the supply, accompanied by a gradual fall of pressure. The cylinders were fixed vertically to the fore-end of the reservoir, and they worked to a crank-shaft below, from which the power was transmitted by spur-gearing to the nearest axle. The reservoir contained 60 cubic feet of heated water. It was first filled with cold water, after which a connection was made with the steam-pipe of a large stationary boiler at Carrolton, under a pressure of 200 lbs. per square inch. The cold water was quickly heated up, and raised to a pressure of 180 lbs. per square inch. The connection was then uncoupled, and the hot-water locomotive was ready for work. The exhaust-steam was discharged directly into the air, making clouds of moist white vapour. It was reported, in 1875, that the hot-water locomotives were in constant and successful operation. The tramway is about six miles in length. From the centre to the outskirts of the city, the cars are worked by mules, which are then exchanged for the engines. With one replenishment of the reservoir at Carrolton, the locomotive can make the double journey to New Orleans and back, and have a pressure remaining of 50 lbs. per square inch.

By observation it was found that when the atmospheric temperature fell to 40° F., the temperature of the water, though it was 160° higher, only fell about 3° F. per hour.

### EAST NEW YORK AND CANARTIO.

In October 1873, a trial of a hot-water locomotive was made between East New York and Canartio, a distance of 3½ miles. The reservoir was 3 feet 10 inches in diameter, and 10 feet long, on two pairs of 30-inch wheels, coupled. There were two steam-cylinders, 8 inches in diameter, with a stroke of 12 inches. The exhaust-steam was discharged into two condensers, one for each cylinder, fitted with 38 condensing tubes ⅝ inch in diameter, and air-pumps for creating a partial vacuum. The weight of the engine was 4 tons 3 cwt.; that of the car which was drawn by it was 7½ tons, empty, and was estimated at 12½ tons, loaded with 120 passengers. The locomotive, with the car, performed the run of 3½ miles to Canartio, on falling gradients, in 12¾ minutes, at the rate of 16½ miles per hour, whilst the pressure in the reservoir fell from 180 lbs. at the beginning of the trip, to 108 lbs. per square inch at the end of the trip. The train stopped for nine minutes at Canartio, and during this time the pressure fell to 104 lbs. The return trip, on rising gradients, was made in 17 minutes, being at the rate of 12¼ miles per hour, when the pressure fell to 45 lbs. per square inch. It is stated that the machinery of this engine was poorly designed and constructed: obviously the condenser was quite insufficient.

A few months later another hot-water locomotive working on the Canartio line, was tested by Mr. R. H. Buel and Mr. H. L. Brevoort. The results of their trials were recorded in a report written by Mr. Buel, in January 1874.[1] The reservoir of the locomotive was 3 feet 1 inch in diameter and 9 feet long, having a steam-dome 12 inches in diameter and 2 feet high. The cylinders were vertical, 5 inches in diameter, with a stroke of 7 inches, fitted with slide-valves and link-motion. The power was transmitted to one of the axles by a spur pinion of 26 teeth on the crank-shaft, gearing into a wheel of 46 teeth on the axle. There are four 30-inch wheels on two axles. The reservoir was covered with cement and felting, and the steam-cylinders were heavily felted. A 2-inch pipe, perforated with small holes, lay along the reservoir, near the bottom, for nearly the whole length; and steam was admitted from a stationary boiler, through this pipe, for the purpose of heating the water.

---

[1] Published in *The Engineer*, February 20, 1874, page 135.

The reservoir was half full of water at the commencement of the trip, of 4·40 miles, and the pressure of steam was 142 lbs. per square inch. The pressure of the steam during the trip was as follows:—

| Time. P.M. | Pressure. lbs. per square inch. |
|---|---|
| 3.35 | 142 |
| 3.37 | 132 |
| 3.38 | 124 |
| 3.39 | 124 |
| 3.51 | 102 |
| 3.53 | 97 |
| 3.55 | 89 |
| 4.4 | 70 |
| 4.7 | 66 |
| 4.10 | 52 |
| 4.13 | 48 |
| 4.15 | 44 |
| 4.21 | 29 |
| 4.24 | 22 |
| Average pressure | 81·5 lbs. |

The total time running the trip, 4·40 miles, was 49 minutes, of which the time actually running was 35½ minutes. The average speed whilst running was 7·44 miles per hour. The average speed of the crank-shaft was 147·4 turns per minute, giving a speed of piston 172 feet per minute. Mr. Buel calculated, from the pressures in the reservoir, that 210 pounds of water was evaporated and consumed during the trip, being at the rate of 48 pounds per mile run. The engine was worked in full gear, and the steam was wire-drawn by the regulator. The average initial pressure in the cylinder was found, from indicator-diagrams, to be 23·52 lbs. per square inch; the average terminal pressure was 19·86 lbs.; the average back pressure was 5·15 lbs.; the average effective pressure was 17·86 lbs. per square inch. The indicator power was 3·61 horse-power. Mr. Buel estimates that the quantity of steam manifested in the cylinders, according to the indicator-diagrams, amounted to 147·15 pounds, or 70 per cent. of 210 pounds, the calculated quantity evaporated. The circumstances under which the steam was employed in the engine were obviously unfavourable. The steam was not worked expansively to any degree; and much of it was condensed in the cylinders. The speed of the pistons was too low, and, even with such low speed, the back pressure on the pistons amounted to 5·15 lbs. per square inch, or 22¼ per cent. of the positive pressure above the atmosphere.

### BAXTER.

In 1872, Mr. Baxter, of Newark, U.S., brought out a steam-car, fig. 116, in New York. It was placed on four 30-inch chilled wheels, at 7-feet centres, driven by a steam-engine with compound cylinders, placed together under the floor. The steam was supplied from a vertical boiler, 26 inches in diameter, and 4½ feet high. It is stated that this steam-car worked well, taking 52 passengers, ascending an incline of 1 in 13. It was also noiseless.

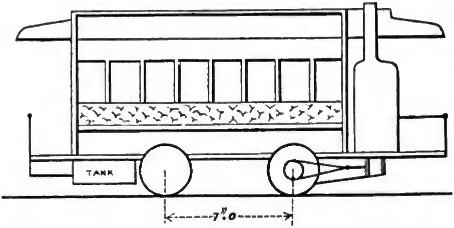


Fig. 116. Steam-car, by Mr. Baxter, 1872. Scale, $\frac{1}{96}$.

---

### Grantham.

Mr. John Grantham, impressed with the necessity for substituting steam-power for horse-power, patented a system of steam-car in 1871, consisting of an ordinary tramway-car, in which the propelling power was to be lodged and applied at the middle of the length of the car. In 1872 he had a steam-car, fig. 117, constructed; of which the car proper was made at the Oldbury Carriage Works, and the engines and boilers by Messrs. Merryweather & Sons, to Mr. Grantham's design. This was the first steam-car for tramways constructed in England. A boiler-chamber was constructed at each side of the body, to hold two upright boilers, leaving a central passage free for circulation in and out at either end of the car, or from end to end. The boilers were constructed on the Field system; with pendent water-tubes, having internal circulating tubes. They were 18 inches in diameter, and 4 feet 4 inches high; the firegrate of each boiler was 15 inches in diameter. The machinery was placed below the floor. The steam-cylinders were 4 inches in diameter, with a stroke of 10 inches, and were connected to a single pair of driving wheels, 30 inches in diameter. The car had four wheels, placed at 10 feet apart between the axles. One axle was for driving; the other axle had one wheel loose, on a sleeve, so that the wheels could revolve independently of each other. The car, over all, was 30 feet in length; it held seats for 44 passengers—20 inside, and 24 outside. The weight, empty, was 6½ tons. Early in 1873, the steam-car was put to work experimentally on a short piece of level railway, 350 yards long, at West Brompton, where it worked for some time satisfactorily enough with steam of 90 lbs. pressure:—traversing the line at an average speed of 11 miles per hour, including

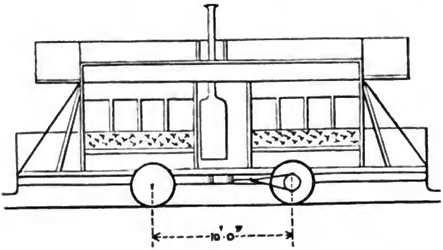


FIG. 117. Steam-car, by Mr. John Grantham, 1872.

the starting and the stopping. But, though a steam-car may do well on a railway, it may fail on a tramway, on which the resistance is much the greater. Thus is to be explained the failure of the Grantham car when it was tried in November, 1873, on a portion of the London Tramways, between Victoria Station and Vauxhall Bridge; possibly, also, as *The Engineer* remarked, because of difficulties in firing, due to the crowded state of the car.

The car was removed to the Wantage Tramway, where it was put to work. But it did not generate sufficient steam for working the inclines and curves of the line, which are severe. The Wantage Tramway is two miles long; the steepest gradient is 1 in 47 for 350 yards, and its quickest curve has a radius of only 75 feet. The insufficient performance of the boilers, and the danger of isolated boilers, unfitted the Grantham car, as first constructed, for employment on ordinary tramways. It was altered under the advice of Mr. Edward Woods. The boilers were taken out, and a single large vertical boiler, constructed by Messrs. Shand, Mason, & Co., with numerous small water-tubes, laid nearly horizontally, was substituted. This new boiler, more fully described below, like the old boilers, was placed in the middle of the car, nearer one side than the other, completely boxed off, and leaving a passage or thoroughfare towards the other side between the first-class and second-class ends of the car. New wheels of smaller diameter, 24 inches, were substituted for the original wheels. One pair of the wheels is used for driving, and the other pair, as before, had one loose wheel, to ease the passage on curves. The car is driven from either end by removable levers, by means of which the driver possesses entire control of its movements. It is 27 feet 3 inches long, 6 feet 6 inches wide, and 11 feet 1 inch high. The net weight of the car, empty, is 6½ tons, and with a supply of coke and water, 8 tons. It can accommodate 60 passengers, making a load of, say, 5 tons, and a gross weight of 13 tons loaded.

The following estimate of the cost of working tramways by the Grantham steam-car, is based on the results of experience on the Wantage Tramway. It is assumed that a mileage amounting to 26,260 miles is run during the year,—equivalent to 72 miles per day, although, as a matter of fact, the daily mileage run on the Wantage line has been less than 40 miles.

WANTAGE TRAMWAY.

*Estimated cost of working Grantham's steam-car.*

| | | £ | *s.* | *d.* |
|---|---|---|---|---|
| 1 engine-driver @ 35*s.* per week<br>1 stoker @ 25*s.* „<br>1 conductor @ 20*s.* „ | 80*s.* | 208 | 0 | 0 |
| Fuel, 7 lbs. of coke per mile for 26,260 miles = 82 tons @ 15*s.* . . . . . . . . | | 61 | 10 | 0 |
| Oil, tallow, wash, and sundries, @ ¼*d.* per mile, for 26,260 miles . . . . . . . . | | 27 | 7 | 1 |
| Water at 1*s.* per day . . . . . . . | | 18 | 5 | 0 |
| Repairs of car and machinery, at 1*d.* per mile, for 26,260 miles . . . . . . . . | | 109 | 8 | 4 |
| Total cost . . . . . . . . | | £424 | 10 | 5 |

or 3·88*d.* per mile-run.

The next steam-car constructed on Grantham's system, fig. 118—though the leading speciality of the system nearly vanishes in the car last constructed—comprised a few further improvements, made on the recommendation of Mr. Woods. A four-wheel bogie was substituted for the independent wheels, and the boiler and machinery were placed at one end of the car. The car was constructed by the Starbuck Car & Waggon Co., Birkenhead, to work on the Vienna Tramways. The machinery and the boiler were supplied by Messrs. Shand, Mason, & Co. The boiler was one of their inclined water-tube boilers, like those which are employed by them in the construction of fire-engines. The fire-box is upright; the water-tubes, which are of small diameter, are arranged in layers, slightly inclined, which cross each other, one above another. The machinery is below the platform, and the water-tanks are placed under the seats of the car. The cylinders are 6 inches in diameter, with a stroke of 9 inches; the driving-wheels are 2 feet in diameter; and the bogie-wheels are 20 inches, placed at 3 feet between the centres of the axles. The distance from the centre of the driving-axle to that of the bogie is 8 feet. On this working base of 8 feet, there is a total length of car equal to 28½ feet, of which the length of the

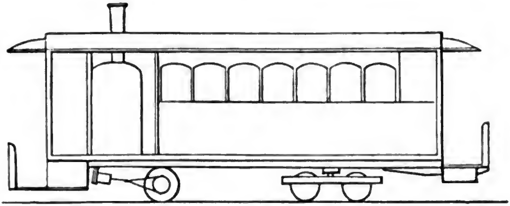


FIG. 118. Grantham Steam-car, 1876.

body is 23½ feet, comprising 14 feet for the accommodation of 24 passengers, and 9½ feet for the boiler-room. The total weight is about 7 tons gross, with passengers, of which there are 3 tons on the driving-wheels, and 4 tons on the bogie. The price of the steam-car is £750.

This car was tried on the Hoylake and Birkenhead Tramway, on May 11, 1876. The tramway is 2½ miles long, with curves of 35 feet radius, and a maximum gradient of 1 in 19. The car made three complete double journeys, or a total running of 15 miles, with a load of 45 passengers. The working pressure in the boiler was 100 lbs. per square inch. The ordinary speed, whilst running, was about 10 miles per hour; but the speed, when tested, occasionally reached double that rate. The car ascended the incline 1 in 19; but it could not have started on the incline if it had been stopped on it.

A trial of this steam-car was made on reaching its destination, on the Vienna Tramways, over a piece 2·40 miles long, between the Semmering Tramway Station and the Central Cemetery, on July 28, 1876. The distance was traversed in 15 minutes, or at the rate of 9½ miles per hour, including stoppages. The steepest gradient was 1 in 48, which was ascended at a speed of 14 miles per hour. The boiler, though a rapid generator of steam, is, for the purpose of a tramway-motor, too limited in water-room; and it demands skilled management, to maintain the pressure free from violent fluctuations. The regular working speed is from 10 to 12 miles per hour.

In Mr. Woods' latest design of the Grantham steam-car, the distance between the centres of the driving-axle and the bogie has been increased to 10 feet.

---

### Perkins.

In 1874, a tramway locomotive was constructed on the system of Mr. Loftus Perkins, by the Yorkshire Engine Company, for the Belgian Street Railway Company, Brussels. It was worked by steam of a pressure of 500 lbs. per square inch, with compound cylinders, of which the first cylinder was single-acting, $2\frac{9}{16}$ inches in diameter, and the second cylinder was double-acting, $4\frac{3}{8}$ inches in diameter. Thence the steam was exhausted into an air-surface condenser, consisting of two assemblages of vertical $\frac{1}{2}$-inch copper tubes, one on each side of the engine, presenting together 700 or 800 square feet of heating surface. The steam was condensed by the cooling action of the atmospheric air which circulated about the outside of the tubes. The upper ends of the tubes were closed, with the exception of a small aperture, about $\frac{1}{16}$ inch in diameter, left for the escape of possible vapour. The boiler was constructed of bent iron tubes, $2\frac{1}{4}$ inches diameter inside, and $\frac{3}{8}$ inch thick; it had been proved to a pressure of 2,500 lbs. on the square inch, or 167 atmospheres. Coke was the fuel used, and the force of draft was simply that due to the height of the chimney. The wheels were 2 feet in diameter; the axles were $2\frac{1}{2}$ inches in diameter, swelled to a diameter of $3\frac{1}{4}$ inches at the middle. The speed of the crank-shaft was reduced by toothed-wheel gearing, in the ratio of four to one; and the motion was taken off the second shaft to the wheels by coupling-rods. The weight of the locomotive was only 4 tons, in working order. The scantling of its parts appears generally to have been scarcely sufficient. The crank-shaft, for example, was only 1⅝ inches in diameter. Mr. Cramp states, that in a preliminary trial of this engine, with its load, in the end of 1874, on the Manchester and Sheffield Railway, a speed of 15 miles per hour was attained, on gradients of from 1 in 200 to 1 in 80.

The engine was sent to Brussels, where it had the duty of drawing a one-horse passenger-car. M. Vaucamps, director of the Belgian Street Railways, writing upon the results of trials in the end of 1874, stated that the system was perfect: 'In fact, no smoke, no escape of steam into the atmosphere, no noise, no feeding of water during the trip, nor even, if needful, for several days.' M. Spée, writing in December 1875,[1] did not form quite so favourable an estimate; but 'he was convinced that this motor, slightly modified, would answer perfectly. It would be necessary to employ two cylinders at least [probably he meant two systems of compound cylinders]. The pressure, 35 atmospheres, in consequence of which it is very difficult to maintain the joints, would not appear to be indispensable. The condenser,' he added, 'does not act efficiently, for the outer ranges of tubes, screening the others, prevent their being sufficiently cooled.' M. Vaucamps appears to have afterwards adopted similar views, for, in 1875, he adapted two systems of compound cylinders to the engine, with a mode of coupling by frictional gearing, heavy and complicated, for moving the locomotive either way; this gearing gave rise to violent shocks. 'After having tried this coupling-gear for some time,' says M. Spée, 'M. Vaucamps resolved to take the machine to pieces, and sell it as old metal.'

---

[1] '*Exploitation des Chemins de Fers Américains par Traction Mécanique*,' page 12.

Mr. Perkins's tramway locomotive is illustrated in Plate XIII., according to the designs and details recently worked out by himself. This engine will be afterwards described.

### SOCIÉTÉ MÉTALLURGIQUE.

The Société Métallurgique et Charbonnière, Belgium, according to M. Spée, constructed, in 1875, a locomotive fitted with a three-cylinder engine on Brotherhood's system. The high speed of the engine was, in the first design, reduced by means of an endless-screw and wheel, with a view to the prevention of noise. But this gearing broke down several times, and the friction and the wear were found to be so considerable, that in a second design the reduction of speed was effected by means of spur-gear. From cranks on the last shaft of the motion, the wheels were turned by connecting-rods. A fly-wheel, also, has been fixed on the first shaft of the engine, for the purpose of preventing the noise of the gearing. The locomotive resembles in external appearance an omnibus; the body is 7 feet 2 inches long, and 6 feet 8 inches wide; the total length of the frame is 11½ feet. There are four wheels, coupled, of which the axles are 3 feet 7 inches apart between centres. The boiler is of the Belleville type, 'inexplodable,' consisting of water-tubes arranged for rapid evaporation, with only the natural draught of the chimney. It is fed automatically by a donkey-engine. The steam is slightly superheated, and is exhausted into a surface-condenser, whence the remaining uncondensed steam mixed with the air is discharged into the chimney. The principle of the condenser consists in the division of the exhaust-steam into a number of jets, which draw, each by a conical nozzle, currents of air to condense the steam. The locomotive weighs 6 tons, and it carries a supply of coke and water for 4 or 5 miles. It was found that the condensation was imperfectly effected when the atmosphere was not warm or dry, and in another locomotive of the same kind, constructed subsequently, the area of the condensing surface has been extended to five times that of the surface in the first engine. To facilitate the lubrication of the cylinders, they are placed horizontally on the platform near the conductor. The stoker, who takes his place within the covering, attends to the fire and the water.

In August 1875, a tramway-locomotive, constructed by Mr. A. Kohl, a Danish engineer, was tried in Copenhagen, on the tramway worked by the American Omnibus Company. It weighed, in working order, upwards of 5 tons, and it drew two American tramway-cars filled with passengers.

---

### SMITH & MYGIND.

In December 1875, a tramway-locomotive, constructed by Messrs. Smith & Mygind, of Copenhagen, was put to work on the tramways of Copenhagen, drawing passenger-cars. The boiler, according to M. Spée, was of the locomotive type, and compound cylinders were employed. The exhaust-steam was condensed in a surface-condenser, holding a quantity of water sufficient to last an hour.

### FRANCQ.

M. Léon Francq, in 1875, patented a hot-water locomotive containing some improvements on Dr. Lamm's engine. The reservoir is 3 feet 9 inches in diameter, and about 6 feet 8 inches long; it is filled for about three-fourths of its capacity—50 to 60 cubic feet—with water; which is put in communication with one or more stationary boilers, from which steam is admitted through a perforated pipe into the water. The steam in the boilers has a pressure of 156 lbs. per square inch; the pressure obtained in the reservoir is 135 lbs. per square inch. If the communication were continued for a sufficient length of time, the pressure in the reservoir would become equal to that in the boiler; but the rate of absorption of heat and rise of pressure, decreases gradually as the pressure is elevated, and for economy of time it is found expedient to arrest the process of heating-up at a lower limit of pressure and temperature than that in the boilers. The steam from the reservoir is admitted to an intermediate chamber, where it is maintained at a fixed pressure, the degree of which is adjusted by means of a throttle-valve. There is a pair of vertical cylinders, about 6 inches in diameter, with a stroke of about 12 inches, which work an intermediate crank-shaft, from which the four wheels are driven by outside coupling-rods. The wheels are about 26 inches in diameter, and the two axles are at a distance of 4 feet 6 inches apart. By a system of double frames, the passage over curves is facilitated. The locomotive is controlled by a brake having eight blocks, which are applied to the wheels successively. The stopping is thus effected promptly and without shock. The exhaust-steam is delivered into two air-surface condensers, one on each side of the car, each consisting of a group of small copper tubes. It is in contemplation to apply three cylinders to work as compound cylinders. The locomotive is heavy: it weighs, empty, 6·50 tons; full, 8·30 tons.

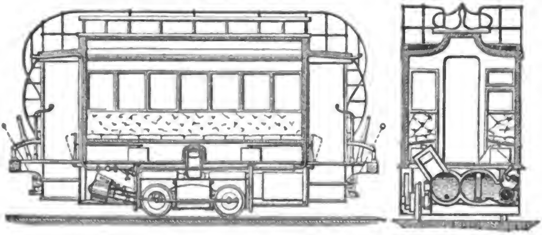
In trials of this engine on the tramway between Saint-Augustin and the Boulevard Bineau—a distance of 2½ miles,—drawing one omnibus of 2 tons weight, with eight passengers—it was observed that the pressure in the reservoir fell from 156 lbs. per square inch to 50 lbs., during the double trip of 5 miles. For the first ten minutes of the service, no exhaust-steam was visible from the engine; but, afterwards, a considerable quantity of steam escaped, and proved an annoyance to the passengers who travelled in a following car drawn by horses.

In the most recently designed engines on M. Francq's system, constructed by M. Cail, the wheels are 30 inches in diameter, and the axles are 4 feet 3 inches apart, that the engine may pass easily over curves of 15 metres, or 49 feet radius. The cylindrical reservoir is of steel plate, ·56 inch thick, and is 1 metre in diameter and 2 metres long, or 3·28 feet by 6·56 feet. The authorised limit of pressure is 213 lbs. per square inch, nearly 15 atmospheres. The reservoir is coated with cork and wood. The regulator is so arranged that the driver may fix, before starting, the maximum pressure of the steam upon the pistons; and that, at the same time, he may reduce the pressure below the maximum, according to the requirements of the engine. The steam is exhausted into a cast-iron box, and thence into a condenser, disposed on the surface of the reservoir, before escaping into the atmosphere.

It may be well to recite the advantages formally claimed for M. Francq's locomotive: 1. The production of steam at a low cost, in a fixed boiler, using coal as it comes from the mine. 2. Reduction of dead weight, since no fuel is conveyed on the engine. 3. Employment of a high pressure for ascending inclines, and no escape of steam in descending inclines. 4. Reduction of the number of attendants, a single man being able to conduct the engine and keep a look out.

### TODD.

Mr. L. J. Todd, early in 1875, constructed a hot-water steam-car, figs. 119, 120, in which the reservoirs and the machinery were placed beneath the floor of the car. There are two reservoirs, having the form of boilers, with domes; each reservoir containing 30 cubic feet of heated water, or a total of 60 cubic feet. The reservoirs are well coated with non-conducting material. The cylinders are 9 inches in diameter, with 8 inches of stroke, connected direct to one pair of the wheels. There are two pairs of 24-inch wheels, coupled, for adhesion, at a distance of 4 feet 6 inches apart between the axles. The cylinders are surrounded by large jackets open to the heated water, in which they are immersed; and are thus maintained at the maximum temperature in the reservoir. By this means, a superior action of the steam in the cylinder is effected, and the steam is superheated to some extent before it is exhausted. There is no other provision for rendering invisible the exhaust-steam, which simply emerges at the end of the car, under the roof. The body of the car is 14 feet long, and 7 feet wide over all; the extreme length over the buffers is 22 feet 6 inches. Two lines of seats are fixed on the roof; the weight of the car, in working order, is 6½ tons.



FIGS. 119, 120. Hot-water Steam-car, by Mr. L. J. Todd, 1875. Scale, about $\frac{1}{96}$.

### BÈDE.

MM. Bède & Co., of Belgium, constructed a hot-water steam-car, in 1875, to the directions of the Société Générale de Tramways. The reservoirs consist of four small horizontal cylinders placed under the seats, and two upright cylinders placed one on each side of the car, enclosed, and leaving a passage-way within the car between the first-class and second-class compartments. The steam, disengaged in the upper part of the upright cylinders, descends in a pipe through the hot water, to the steam-cylinders. There are three steam-cylinders, 4½ inches in diameter, with a stroke of 14·2 inches, connected to a triple-crank axle, with 28-inch wheels. They are fitted with link-motions. The crank-axle is placed under the middle of the car, which originally had two other axles with 20-inch wheels which were loose on the axles. One of the pair of wheels was removed, and the wheels of the other pair are fixed on the axle. But the wheels are not coupled. The reservoir contains 50 cubic feet of water heated to 365° F., for an effective air-pressure of 10 atmospheres or 162 lbs. per square inch. The reserve of heat is sufficient to last 50 minutes at the ordinary speed on tramways, with a load of 1·60 tons. The car runs with facility on curves of 40 feet radius; and ascends an incline of 1 in 28, with a pressure of 4½ atmospheres, or 66 lbs. per square inch. The car stops and starts quickly and without shock. The exhaust-steam is discharged into a chamber so arranged as to separate water from the steam, and the sound of the escaping steam is scarcely audible.[1]

---

[1] These particulars are borrowed from M. Spée.

It appears from recent reports that this engine has worked daily with regularity and success in Belgium.[1] The charging of the reservoir is renewed every two hours, and is done in a quarter of an hour. The cylinders constituting the reservoir are covered with woven glass and lagging. A tank is filled with cold water, for condensing the exhaust steam; there are now, it is said, four horizontal steam-cylinders, two at each end, all of which are brought into action in ascending the steepest incline already noted. The speed attained is ten miles per hour, on a level. Suet is used for lubrication, to obviate the odour of oil. The sockets for the driving and other levers are in duplicate, one set at each end of the car. The engine is about (September 1877) to undergo a few alterations, to improve the arrangement of the machinery.

### MERRYWEATHER.

Messrs. Merryweather & Sons, whose long and successful practice in the construction of steam fire-engines, enabled them readily to appreciate the special requirements of light locomotives for the service of tramways, were early engaged in the design and manufacture of tramway-engines. It has already been noted that this firm constructed the machinery for the first steam-car made for tramways in England, in 1872, to the designs of Mr. Grantham. They secured their first patent for tramway-engines of their own design in April 1875. The first engines on this system constructed by them, were to the order of Mr. G. P. Harding, for working the line of tramway in Paris, 4½ miles long, between the Bastille and the Mont Parnasse railway station. The first engine was started about the month of November, 1875, and there are now (January 1878) 36 of Messrs. Merryweather's engines regularly at work on that line. There are also 10 of their engines on the line from the Bastille to St. Mandé. Many improvements, naturally, have been made in the design and construction of the engines. In the earliest engines, a portion of the exhaust-steam was discharged into the ash-pan and passed through the fire, that it might be superheated, and, mixing with the remaining portion, discharged direct into the chimney, reduce the visibility of the escaping steam.

---

[1] *The Foreman Engineer and Draughtsman*, September 1857, page 138.

In their more recent designs, Messrs. Merryweather dispose of the exhaust-steam by means of an 'auto-absorbing' apparatus—a simple arrangement in which the steam is condensed by cold water. Their locomotive will be afterwards fully described according to the latest developments.

### HUGHES.

Finally, Mr. Henry Hughes brought out, early in 1876, a tramway locomotive. 'The result of my experiments,' he said, on his examination as a witness by the committee on Mechanical Power on Tramways, 'is that I have produced an engine of the ordinary locomotive type, which can be worked without showing any steam, which is practically noiseless, and in which we can keep up the steam without the aid of a blast; and it shows no smoke because we use coke as a fuel. It is covered in similarly to an ordinary car, and consequently does not frighten horses more than ordinary cars do.' These are, concisely stated, the conditions for the success of mechanical power on tramways. The means for condensing the exhaust-steam, which is the novel feature of this engine, was patented by Mr. Hughes, in January 1876. Each blast of exhaust-steam is, by an automatic action, condensed as it issues from the exhaust-pipe, by a shower of cold water, let off in regulated quantities at the instant of the exhaust. The exhaust-steam, arriving by a branch from the exhaust-pipe, blows open a valve on the end of the branch, and escapes into a small chamber—the condenser. By the same impulse, another valve in the bottom of a water-tank, connected with the exhaust-valve, and moving simultaneously with it, is opened, and discharges water into the condenser. The exhaust-steam is condensed by the water, a partial vacuum is formed in the condenser, and the water-valve is consequently closed by the external pressure. The resulting mixture, consisting of hot water, is discharged at a temperature of 170° F., into a receiving tank. Within this limit of temperature, there is not much visible vapour disengaged from the discharged water. When the temperature is allowed to rise above 180°, a good deal of visible vapour escapes. The supply of feed-water for the boiler is drawn from this tank, and the remainder of the hot water is rejected during the journey, or at the end of the trip. It is stated that, on a level line, the condensing water is consumed at the rate of from 25 to 30 gallons per mile. The fire is made up at the beginning of the trip, and is not touched during the passage. According to Mr. Hughes, a fire will last for a ten-mile run without requiring fresh stoking.

The first public trial of Mr. Hughes' tramway locomotive was made on the Leicester Tramways, on March 27, 1876. A run of four miles was made, a portion of which was on an ascending gradient of 1 in 22. The engine had two 6-inch cylinders, having a stroke of 12 inches, connected direct to four coupled wheels, 2 feet in diameter, on a wheel-base of 4 feet. The boiler, of the locomotive type, had 120 square feet of heating surface. The whole of the boiler and the machinery was enclosed in a wooden structure resembling a section of a tramway-car; the wheels and the side-rods were concealed by sheet-iron plates. The chimney rose through the roof of the car, and by its length sufficed for the natural draft required to keep up the steam, which was maintained at a pressure of about 120 lbs. per square inch. The furnace was supplied with a sufficient quantity of fuel to last the journey. The quantity of condensing water carried amounted to 300 gallons, which, it is said, would suffice for a trip of six miles on ascending inclines, in cold weather. The weight of the steam-car, in working order, was about 5 tons.

The locomotive was coupled to a one-horse car, constructed to carry 16 inside. During the trial, it carried 25 persons, and the total weight of the car, with its load, must have been about 3½ tons, making the gross weight of the train about 8½ tons. The speed was generally about 8 miles per hour, and one or two steep inclines on bridges were steadily surmounted, at a lower speed. During the whole of the trip, there was no visible escape of steam, except on one occasion, in surmounting a steep incline, when a little steam escaped, which quickly disappeared.[1]

The same engine, according to Mr. Hughes, was used on the Leicester line every day for some weeks, on passenger traffic. The average pace was six miles per hour.

Mr. Hughes' engines have also been at work experimentally on the tramways at Edinburgh and at Sheffield, and on the Vale of Clyde Tramways at Glasgow. The traffic of this line is worked by steam-power, under a contract with Mr. Hughes, made early in 1877. The locomotives, six in number, weigh, empty, 4¾ tons; with fuel and water, 6 tons. They work up to a pressure in the boiler of 150 lbs. per square inch; but the average pressure is from 100 lbs. to 120 lbs. From the experience already acquired of the performance of these engines at Glasgow, it has been estimated that the cost for working 70 miles per day per engine, for fuel, oil, water, attendance, and driving, amounts to about 2·30*d.* per mile-run.

### BALDWIN LOCOMOTIVE WORKS.

Reverting to America, a steam-car was built at the Baldwin Locomotive Works, in 1875; and was experimentally worked on the Atlantic Avenue Railway (Tramway) at Brooklyn, for the first six months of 1876. It was run and kept in order by one engineer during that time, consuming from 7 lbs. to 8 lbs. of coal per mile run. Night and morning, it drew behind it an additional car with passengers from and to New York. On several occasions, a speed of 16 or 18 miles per hour was attained with it. In June 1876, the steam-car was removed to Philadelphia, where it was worked on the Market Street line till nearly the date of closing the Centennial Exhibition. The car was constructed with steam-cylinders under the body, connected to a cranked-axle, to which the fore-wheels were coupled. The hind-wheels were free. The machinery was fixed to an iron bed-plate bolted to the wooden framing of the car. This mode of construction was found to be objectionable, as the framing was not strong enough for the purpose. The crank-axle, also, was subject to occasional breakage.

---

[1] The particulars of this trip are derived from *The Engineer*, March 31, 1876, page 232.

In the end of 1876, therefore, the steam-car was removed to the works of the Baldwin Company to be reconstructed. An iron framework was made, on which an upright boiler and the machinery were fixed, independent of the body of the car, which was bolted down to it; and outside horizontal cylinders were employed. In this way, existing car stock could be utilised:—bolting down the bodies to an engine-frame adapted to receive them and carry them. The throttle-valve was placed close to the cylinders—a good idea—having the advantage of promptly stopping and starting the engine. The car was carried on rubber springs, with cross equalising-beams; the motion was smooth, free from interference by the action of the machinery. The boiler was of steel, double-riveted, and was calculated to support with safety a steam-pressure of 300 lbs. per square inch. But, a pressure of 90 lbs. was sufficient to move the loaded car over the steepest inclines on the Market Street line, which are about 1 in 22, without ever 'stalling' or requiring assistance. The reconstructed steam-car, which was named the 'Baldwin,' was replaced on the Market Street Tramway on March 21, 1877; it worked regularly for four weeks, to April 18:—running 88 miles per day, seven days in the week.

The quantity of fuel, coal, consumed by the steam-car, amounted to 4,950 pounds in seven days, running (7 × 88 =) 616 miles:—at the rate of 8·03 pounds per mile-run. The car did not require any repair during the four weeks' run. The actual daily expenses, with estimated cost for maintenance and interest, were as follows:—

### BALDWIN STEAM-CARS.

*Cost of Running one Steam-Car one day.*

| | Dollars. | | *s.* | *d.* |
|---|---|---|---|---|
| Fuel, 88 miles, at 8 lbs. per mile, equal to 704 lbs., @ 4 dollars per ton . . | 1·26 | or | 5 | 3 |
| Oil, waste, and tallow . . . . . | ·25 | ,, | 1 | 0½ |
| Wages of engineers, 16 hours @ 25 cents. | 4·00 | ,, | 16 | 8 |
| Repair and maintenance of car and machinery . . . . . . | 1·00 | ,, | 4 | 2 |
| Working cost . . . . . | 6·51 | ,, | 27 | 1½ |
| Daily interest on cost of steam-car, 3,000 dollars, or 625*l.* @ 6 per cent. per year . . . . . . . . . | ·49 | ,, | 2 | 0½ |
| Total cost per day (4*d.* per mile-run) | 7·00 | ,, | 29 | 2 |

The Baldwin Company also constructed a tramway locomotive, having boilers and cylinders of the same capacity as those of the steam-car, on an iron frame; of which, with water-tanks, the total weight was 12,000 pounds, or 5·35 tons. The whole of these masses were carried within the wheel-base, so preventing rocking and pitching. A locomotive of this class was constructed in 1876, for the Citizens' Railway of Baltimore, of which the maximum gradients are 1 in 14·3. It was capable of drawing one car up the incline, but it had not sufficient power to take up two cars. A second engine, weighing about 7·2 tons, was built and delivered in December 1876. During severe snow-storms, it ascended the maximum incline, drawing one car, with 100 passengers, when the tracks were covered in places with a mixture of snow and dirt to a depth of 8 or 10 inches. It could, without difficulty, draw a loaded car, for taking which, otherwise, four horses were required. In better weather, the locomotive worked regularly—taking two cars up the incline.

The following is a statement, for comparison, of the cost of running horse-cars, based on the reports of various tramway companies in Philadelphia:—

### HORSE-CARS IN PHILADELPHIA.

*Cost of Running one Two-Horse Car one day.*

| | £ | s. | d. |
|---|---|---|---|
| First cost of one car, 1,000 dollars, or . . . | 258 | 6 | 8 |
| Ditto 9 horses, @ 140 dollars, or £29 3s. 4d. | 262 | 10 | 0 |

| | *s.* | *d.* |
|---|---|---|
| Feed and stable expenses (feed, straw, hostlers, stable boss, medicines), of 9 horses, @ 46 cents., or 1*s.* 11*d.* . . . . . . . | 17 | 3 |
| Shoeing of 9 horses, @ 6 cents., or 3*d.* . . . | 2 | 3 |
| Maintenance of harness of 9 horses, @ 2 cents., or 1*d.* . . . . . . . . . . . | 0 | 9 |
| Maintenance of 9 horses, @ 33⅓ per cent. per year, for depreciation, equivalent per day for 9 horses to . . . . . . . . | 4 | 9½ |
| Maintenance of car . . . . . . . . | 1 | 8 |
| Wages of driver . . . . . . . . | 7 | 3½ |
| Daily interest on cost of car and nine horses, @ 6 per cent. per year . . . . . . . | 1 | 6½ |
| Total . . . | 35 | 6½ |

Compared with this amount, the cost of running a steam-car, before estimated at 29*s.* 2*d.* per day, shows a difference of 6*s.* 4½*d.* per day, or 18 per cent., in reduction on the cost for horse power.

## Ransom.

Mr. Louis Ransom's steam-car is so constructed that the machinery may be readily adapted to existing cars. A double-crank axle with driving-wheels for inside cylinders, is substituted for one pair of ordinary wheels, and the machinery is placed horizontally under the floor. The two cylinders are cast in one piece, connected to the driving axle by means of three bars, which have bearings on the axle, and form the framing of the engine. The valve-gear consists of a rocking expansion-link, vibrating on a pivot at the middle, and worked by two eccentrics. The valve-spindle is connected to the expansion-link by a radius-link, which is shifted vertically for reversing and for varying the degree of expansion. The forward end of the engine-frame, at the cylinders, is supported by a loop pinned to the bottom of the body. By this arrangement, the engine is suspended on three points, and is easily removed for the purpose of repair. Light repairs may be made by merely detaching the fore-end of the frame from the body, and letting it hang from the crank-axle. The machinery is accessible for general purposes through trap-doors in the floor. It is enclosed in a casing made so perfectly dust-tight that even after having run all day through dusty streets, the engine is free from dust, and is actually covered with drops of water, being the slight quantity of steam condensed which escapes from the stuffing-boxes. The boiler is placed a little forward of the front axle; The water-tank is under the floor at the rear end. the body—for passengers—is nearly equally divided forward and aft of the hind axle. To quell the noise of the exhaust-steam, the steam is passed through a muffler, consisting of a box filled with balls or pebbles.

The body of the car is 16 feet long, having seats for 22 passengers. The length of wheel-base is 7 feet—longer than what is customary, but the car runs by so much the more steadily. It is said that there is less *teter* in passing over rough or uneven places in the line, although the resistance on curves is greater, than with a shorter base. The cylinders are 5¼ inches in diameter, with a stroke of 14 inches. The boiler is upright, 3 feet 1 inch in diameter, and 4 feet 8 inches high, made of one sheet of No. 1

charcoal hammered iron; it contains 300 upright flue-tubes, 1¼ inches in diameter, and 12 inches long, making up a heating surface of 116 square feet, for a grate-area of 6½ square feet. The pressure in the boiler is 120 lbs. per square inch; the testing pressure was 200 lbs. The steam-room has 26 times the capacity of one cylinder of the engine. The car is fitted with a steam-brake, having a cylinder 3½ inches in diameter, with a stroke of 8 inches; the piston-rod is extended with a rack, gearing into a toothed sector linked to knuckle-jointed levers, by which the brake-blocks are forced against the inner edges of the wheels. The steam-valve for the brake is thrown open by the same movement which closes the regulator.

In January 1876, one of the Ransom steam-cars, constructed by Messrs. Gilbert, Bush, & Co., Troy, N.Y., was placed on the Coney Island Railroad, 4½ miles in length, where it ran 81 miles per day for five months. The double trip of nine miles was made in 40 minutes, at a gross average speed of 13½ miles per hour. After each double trip, the steam-car was at rest for 50 minutes. The quantity of coal consumed per day, as fuel, amounted to 600 pounds per day; equivalent to 7·4 pounds per mile-run. The total cost for running 81 miles per day was estimated at 8·31 dollars, or 34*s.* 7½*d.* per day—at the rate of 5·13 pence per mile-run. The engine was sold, and went to work on the Onondaga Valley Road, Syracuse, N.Y.

Six Ransom steam-cars were placed on the Market Street line, Philadelphia, on March 21, 1877, to work on the Baring Street branch, on which the maximum inclines are at the rate of 1 in 22, with many curves. Though seated for 20 passengers, these cars have frequently carried 50 passengers. Some difficulties have been encountered in running these steam-cars, which appear to have been scarcely able to cope with the gradients and curves of the Baring Street branch. In Mr. Ransom's opinion, the engine should have had 7-inch cylinders for this traffic. Besides, the 'peculiar greasy mud' of the city causes the ordinary chilled cast-iron driving-wheels to slip, a defect which Mr. Ransom purposes to remedy by the substitution of tyres of steel for the driving-wheels.[1]

It is reported (September 1877) that steam-cars are about to be established for regular duty on the Third Avenue Tramway, Brooklyn.

---

[1] The above particulars of the performances of the Baldwin steam-car and the Ransom steam-car, are drawn from the reports of the Secretary of the Franklin Institute upon 'Steam on Street Railways,' published in *The Journal of the Franklin Institute*, June and July, 1877.

# CHAPTER II.

## ELEMENTARY DATA FOR MECHANICAL POWER.

### Resistance to Traction.

The first and leading datum which rules the employment of mechanical power, is the resistance to traction on the tramway. On a railway, the resistance, under the most favourable conditions, may be as low as 6 lbs. per ton.[1] But, so low a resistance as 6 lbs. per ton is not to be hoped for on tramways, which, besides the difficulty of the groove in the rail, are exposed to the incidents of mud, stones, and dirt, and are made with many and quick curves. On a straight line of grooved rails, in fair order, the frictional resistance of a tram-car has been found by Mr. Henry P. Holt to vary from a minimum of 15 lbs. per ton of the gross weight of the car, upwards, according to the weather and the state of the way, to more than 40 lbs. per ton:—indicative, certainly, of a bad order of conditions. Mr. Henry Hughes deduced from some experiments a tractive resistance of about 26 lbs.

---

[1] *Railway Machinery*, by D. K. Clark, 1855; page 297.

per ton; often much more, occasionally less. So high resistances as these are readily accounted for, when it is considered that the flanges of the wheels frequently take a bearing on the floors of the grooves, or on the dirt imbedded therein, at the same time that the wheels roll on the surface of the rail; for thus the wheel rolls on two different radii simultaneously, and grinding resistance is excited. Again, whilst the wheel at one end of an axle may be running on the proper bearing surface only, the wheel at the other end may be running on the flange, causing the car to swerve and grind laterally against the rails. Again, the rails may be out of gauge, or out of level, or weak and springy. Lastly, the grooves may be so clogged with detritus that all the wheels may be running on their flanges only; and, besides the illegitimate resistance due to traction on a mud surface, there is the extra resistance due to the wedging of the flanges in the dirt. Car-drivers know the value of a clear groove:—one may tell you that the car requires a horse more power to draw it over clogged rails; another will tell you that it is equivalent to some hundredweights more load, or a ton or two more, according to the clearness of his perceptions. The horse would be the best witness, if he could speak his mind, but, failing his verbal evidence, the dynamometer must be consulted.

It was directly proved by experiments made by M. Tresca, on the tractional resistance of a tramway car, that the groove in the rail was the direct cause of a large portion of the resistance to traction. The car, having four flanged wheels, with its load, was drawn over a portion of the Paris and Versailles

Tramway, laid in macadam, when the tractional resistance amounted to 1-100th part of the gross weight, or 22·40 pounds per ton. Subsequently, two of the flanged wheels, both on one side of the car, were removed and replaced by flat-tyred wheels, by M. Delonchant, the engineer of the tramway; and, in July 1860, M. Tresca repeated the experiment with the half-flanged car:—

| | Tons |
|---|---|
| Weight of 47 passengers, @ 143 pounds | 3·00 |
| Weight of wheels | 0·41 |
| Weight of the car | 2·26 |
| Gross weight | 5·67 |

The length of line traversed was a third of a mile, on a level; and the tractive force, at a uniform speed of 7½ miles per hour, amounted to about 86 lbs., equivalent to 1-147th part of the gross weight, or to 15¼ lbs. per ton. Thus, the removal of two flanges was accompanied by a reduction of the tractive resistance by one-third. M. Delonchant, encouraged by the results of his experience, removed another flanged wheel, running the cars with only one flanged wheel, and three flat-tyred wheels. The result, according to M. Goschler, was that the resistance was reduced a half, as compared with the original car with four flanged wheels. In this proportion, the tractional resistance must have been reduced to about 1-200th part of the gross weight, or to about 11 lbs. per ton.

The Vignoles rail, employed in the tramways of Moscow, incurs a half less resistance to traction than the ordinary grooved rail, according to the report of the engineer, Colonel de Sytenko. The comparatively small tractional resistance of the Vignoles rail is clearly due to the absence of a narrow groove, though it incurs the objection of breaking the continuity of the pavement.

The resistance to traction, at low speeds, increases, of course, with the speed, though slowly. On ordinary railways, under ordinary conditions of curvature and of maintenance, the resistance of engines and trains taken together, as deduced experimentally by the author, may be taken as follows :—[1]

| | | | | |
|---|---|---|---|---|
| 12 lbs. | per ton, | at a speed of | 1 | mile per hour |
| 13 lbs. | „ | „ | 10 | „ |
| 14 lbs. | „ | „ | 15 | „ |
| 15½ lbs. | „ | „ | 20 | „ |

Here it appears that the resistance increases only by 2½ lbs. per ton, when the speed is raised from 10 miles per hour to 20 miles per hour. It may be assumed that, on tramways, the speed will not exceed 15 miles, even when mechanical motive power is employed, and within such a limit the variations of tractive force with the speed are not worth serious consideration.

Considering that the experiment by M. Tresca, from which a resistance of 22·4 lbs. per ton was deduced, was made on a line of tramway laid in macadam, it may be inferred that the resistance on a straight line of tramway, made with grooved rails, well maintained in granite pavement, would not, under similar conditions, have exceeded 20 lbs. per ton.

Mr. Edward Woods, also, estimated the resistance of a tram-car on a level, and, it is presumed, a straight line, at 20 lbs. per ton.

---

[1] *Railway Machinery*, 1855; page 310.

In view of the foregoing observations, it may be concluded that, for purposes of estimation, the resistance of engines and cars on grooved-rail tramways, level, straight, and well maintained, is 20 lbs. per ton; and that, on a line in average condition, with curves, it may occasionally amount to 40 lbs. per ton. An average of 30 lbs. per ton may be taken as a datum for the calculation of the ordinary tractive force to be provided for. These data coincide with the conclusions of Messrs. Merryweather & Sons from their experience with tramway locomotives and cars.

The force required to start a tram-car, to get up the speed, is necessarily greater than the force required to maintain the speed uniformly. It is a variable quantity, for it may be anything that horses may choose to exert, or that engine-drivers may apply. Mr. John Phillips found by experiment that in starting a car by two horses, an initial tractive force of from 500 lbs. to 600 lbs. was exerted on the car:—equivalent, for a gross weight of 5 tons, to from 100 lbs. to 120 lbs. per ton.

## MECHANICAL PROPULSION.

Mechanical propulsion on tramways has been effected by means of steam, and by means of compressed air, worked in cylinders connected to the axles of the locomotive machinery, similarly to a locomotive on a railway. When the effective mean pressure in the cylinders, of which there are usually two, is known, the tractive force at the rails is readily estimated in terms of that force, and the dimensions of the machinery.

Take the case, nearly universal, of two cylinders connected directly to the driving-wheels and their axle. The pressure developed in the pair of cylinders is thus expressed by the equivalent pressure or tractive force, as at the rails :—

$$T = \frac{d^2 L p}{D} \qquad (1)$$

Reversely, the effective mean pressure on the pistons, equivalent to a given tractive force at the rails, is expressed by the formula—

$$p = \frac{D T}{d^2 L} \qquad (2)$$

$d$ = the diameter of the cylinders, in inches.
$L$ = the length of the stroke, in inches.
$D$ = the diameter of the driving-wheels, in inches.
$p$ = the effective mean pressure on the pistons, in lbs. per square inch,
$T$ = the equivalent tractive force at the rails, in lbs.

That is to say :—*to find the Tractive force*—multiply the square of the diameter of the pistons, in inches, by the length of the stroke, in inches, and by the effective mean pressure on the pistons, in pounds per square inch; and divide the product by the diameter of the driving-wheels, in inches. The quotient is the equivalent force, as tractive force, at the rails, in pounds.

*To find the effective mean Pressure.*—Multiply the diameter of the driving-wheel, in inches, by the total equivalent tractive force at the rails, in pounds; and divide the product by the square of the diameter of the cylinders, in inches, and by the length of stroke, in inches. The quotient is the effective mean pressure in lbs. per square inch.

It is understood, of course, that so much of the power developed in the cylinders, as is necessary to overcome the resistance of the machinery of the engine, is intercepted and consumed; and that only the balance of the power is available for tractional action at the rails, and there exerted. But, for the sake of reducing, for purposes of estimation, all the resistances of the engine, as well as those of the car, to one standard for measurement, the whole of the steam-power in the cylinders, as measurable by the indicator, is reduced to an equivalent tractional force at the rail.

EFFECTIVE MEAN PRESSURES IN THE CYLINDERS.

| Period of admission in parts of the stroke | Effective mean pressure in parts of the maximum pressure | Period of admission, in fractions of the stroke | Effective mean pressure, in parts of maximum pressure |
|---|---|---|---|
| Per cent. | Per cent. | | |
| 10 | 15 | 1-10th | 1-7th fully |
| 12½ | 20 | 1-8th | 1-5th |
| 15 | 24 | 1-6th | 1-4th |
| 17½ | 28 | | |
| 20 | 32 | 1-5th | 1-3rd |
| 25 | 40 | 1-4th | 1-25th |
| 30 | 46 | 1-3rd | 1-2nd |
| 35 | 52 | | |
| 40 | 57 | — | — |
| 45 | 62 | — | — |
| 50 | 67 | 1-2nd | 2-3rds |
| 55 | 72 | — | — |
| 60 | 77 | — | — |
| 65 | 81 | 2-3rds | 4-5ths |
| 70 | 85 | — | — |
| 75 | 89 | 3-4ths | 9-10ths |

The effective mean pressure in ordinary steam-cylinders, non-condensing, worked by ordinary valves and link-motion, is given in the annexed table, for various periods of admission, of from 10 per cent. to 75 per cent. of the stroke, and for maximum pressures in the cylinder of from 60 lbs. per square inch to 150 lbs. per square inch.[1]

The proportion of the adhesion-weight, or driving-weight, of the engine, which measures the force of adhesion, available for traction, is very variable—from one-fifth in dry weather, according to the author's experiments on the adhesion upon railways, to one-ninth in damp weather, when the rails may be slippery. To keep within the limits of one-ninth, in the proportioning of engines to their work, ensures the working of the engine in all states of the weather; but a larger fraction may wisely be assumed for the purposes of general estimates, particularly as the aid of dry sand, dropped on the rails, may be invoked, when necessary, for the increase of the adhesive force. A fraction of one-eighth may safely be adopted.

The influence of gradients on the resistance to traction, is easily calculated by multiplying the gross load by the fraction which expresses the rate of inclination. The product is the amount by which the resistance is increased in ascending a given gradient; or, on the contrary, reduced in descending the gradient. To exemplify the effect of an ascending gradient in increasing the resistance, and reducing the available gross load, take such gradients as are equivalent to 30 lbs. per ton, and its multiples, thus:—

---

[1] This table is copied from the author's work on *Railway Machinery*, 1855; page 116.

| Gradient | | | Resistance due to gravity | |
|---|---|---|---|---|
| 1 in 75 | or 1·33 | per cent. | 30 lbs. | per ton |
| 1 in 37 | „ 2·70 | „ | 60 lbs. | „ |
| 1 in 25 | „ 4·00 | „ | 90 lbs. | „ |
| 1 in 18½ | „ 5·40 | „ | 120 lbs. | „ |
| 1 in 15 | „ 6·66 | „ | 150 lbs. | „ |

Taking, as before adopted, a resistance of 30 lbs. per ton, as the normal resistance on a level, the resistance is 30 lbs. more, or is doubled, for an ascending gradient of 1 in 75; and the gross load that can be drawn up the incline, by a given force of traction, is halved:—

| | |
|---|---|
| On a level the available gross load is as . | 1 |
| On an incline of 1 in 75, it is as . . . . | ½ |
| „ 1 in 37 „ . . . . | ⅓ |
| „ 1 in 25 „ . . . . | ¼ |
| „ 1 in 18½ „ . . . . | ⅕ |
| „ 1 in 15 „ . . . . | ⅙ |

As the tramway engine traverses the line in both directions, the work done on each section of the line, whether level or inclined, may, for general purposes, be taken, when averaged for both directions, to be the same as the work done on a level; and it may be assumed that the average period of admission of the steam to the cylinder is 50 per cent. or half-stroke. The average initial pressure in the cylinder may therefore be assumed as that due to the effective mean pressure, that is equivalent to the resistance on a level.

From the foregoing rules and data, the quantity of steam consumed may be calculated for a given distance—per mile-run, for instance; and thence,—in terms of the relative volume of steam,—the quantity of water evaporated, and the quantity of fuel to be consumed. The volume of steam consumed for a stroke of one piston is half the capacity of one cylinder; and there are four halves, or two cylinders, full of steam, consumed for one turn of the driving axle; or,

Steam consumed per turn in cubic inches,

$$= \cdot 7854\, d^2 \times L \times 2;$$

$$= 1\cdot 5708\, d^2 L \quad \text{.........................} (a)$$

$d$ = the diameter of the piston, in inches.
L = the length of the stroke, in inches.
D = the diameter of the driving-wheel, in feet.
S = the volume of steam consumed, in cubic feet, per mile.

The quantity of steam, in cubic inches, consumed per mile is equal to the quantity ($a$), multiplied by the number of turns made in a mile, or by $\frac{5280 \text{ feet}}{3\cdot 1416\, D}$; and if this product be divided by 1728, the quotient is the number of cubic feet consumed per mile. But an addition is to be made for the usual proportion of steam condensed in the cylinder—12 per cent. of the indicated quantity, when the steam is cut off at half-stroke — and the total quantity of steam actually consumed is as follows:—

$$S = \frac{1\cdot 5708\, d^2 L \times 5280}{1728 \times 3\cdot 1416\, D} \times \frac{112}{100}; \text{ or,}$$

$$S = \frac{1\cdot 71\, d^2 L}{D} \qquad (3)$$

that is to say:—*To find the average volume of steam actually consumed per mile, cut off at an average of half the stroke*—Multiply the square of the diameter of the cylinder in inches by the length of the stroke in inches, and by 1·71; and divide the product by the diameter of the driving-wheels in feet. The quotient is the average volume of steam consumed per mile.

The equivalent quantity of water required to be evaporated to form the steam thus calculated is found by dividing the volume of the steam by its relative volume; that is, its volume compared with that of the water of which it consists. Thus:—

$$\text{W} = \frac{1{\cdot}71\, d^2\, \text{L}}{\text{D} \times \text{rel. vol.}} \quad \text{.........} (4)$$

W = the average volume of water evaporated, in cubic feet, per mile.

To express the volume of the water in gallons, multiply the value (4) by 6·2355, the number of gallons in a cubic foot. Thus:—

$$\text{W} = \frac{1{\cdot}71 \times 6{\cdot}2355 \times d^2\, \text{L}}{\text{D} \times \text{rel. vol.}}; \text{ or}$$

$$\text{W} = \frac{10{\cdot}7\, d^2\, \text{L}}{\text{D} \times \text{rel. vol.}} \quad \text{.........} (5)$$

W = the average volume of water evaporated, in gallons, per mile.

That is to say:—*To find the average volume of water as steam consumed per mile, cut off at an average of half the stroke*—1. In CUBIC FEET. Multiply the square of the diameter of the cylinders in inches, by the length of the stroke in inches, and by 1·71; and divide the product by the diameter of the driving-wheels in feet, and by the relative volume of the steam. The quotient is the volume of water in cubic feet.

2. In GALLONS. Perform the same calculation as the preceding, except that the multiplier 10·7 is to

be employed instead of 1·71. The quotient is the volume in gallons.

To facilitate such calculations, particulars of the volume and density of saturated steam are given in the following table, abstracted from the author's larger table.[1]

### Density, Volume, and Relative Volume of Saturated Steam.

| Pressure per square inch above the atmosphere | Density, or weight of one cubic foot | Volume of one pound of steam | Relative volume, or cubic feet of steam from one cubic foot of water |
|---|---|---|---|
| lbs. | lbs. | Cubic feet | Relative volume |
| 0 | ·0380 | 26·36 | 1,642 |
| 5 | ·0507 | 19·72 | 1,229 |
| 10 | ·0625 | 15·99 | 996 |
| 15 | ·0743 | 13·46 | 838 |
| 20 | ·0858 | 11·65 | 726 |
| 22 | ·0905 | 11·04 | 688 |
| 24 | ·0952 | 10·51 | 655 |
| 26 | ·0996 | 10·03 | 625 |
| 28 | ·1042 | 9·59 | 598 |
| 30 | ·1089 | 9·18 | 572 |
| 32 | ·1133 | 8·82 | 550 |
| 34 | ·1179 | 8·48 | 529 |
| 36 | ·1224 | 8·17 | 509 |
| 38 | ·1269 | 7·88 | 491 |
| 40 | ·1314 | 7·61 | 474 |
| 42 | ·1364 | 7·36 | 458 |
| 44 | ·1403 | 7·12 | 444 |
| 46 | ·1447 | 6·90 | 430 |
| 48 | ·1493 | 6·70 | 417 |
| 50 | ·1538 | 6·49 | 405 |
| 52 | ·1583 | 6·32 | 393 |
| 54 | ·1627 | 6·15 | 383 |
| 56 | ·1670 | 5·99 | 373 |
| 58 | ·1714 | 5·83 | 363 |
| 60 | ·1759 | 5·68 | 353 |
| 62 | ·1804 | 5·54 | 345 |

---

[1] See *A Manual of Rules, Tables, and Data for Mechanical Engineers*, 1877; page 387.

Density, Volume, &c., of Saturated Steam—*continued.*

| Pressure per square inch above the atmosphere | Density, or weight of one cubic foot | Volume of one pound of steam | Relative volume, or cubic feet of steam from one cubic foot of water |
|---|---|---|---|
| lbs. | lbs. | Cubic feet | Relative volume |
| 64 | ·1848 | 5·41 | 337 |
| 66 | ·1891 | 5·29 | 329 |
| 68 | ·1935 | 5·17 | 321 |
| 70 | ·1980 | 5·05 | 314 |
| 72 | ·2024 | 4·94 | 308 |
| 74 | ·2067 | 4·84 | 301 |
| 76 | ·2111 | 4·74 | 295 |
| 78 | ·2155 | 4·64 | 289 |
| 80 | ·2198 | 4·55 | 283 |
| 82 | ·2241 | 4·46 | 278 |
| 84 | ·2285 | 4·37 | 272 |
| 86 | ·2329 | 4·29 | 267 |
| 88 | ·2351 | 4·25 | 265 |
| 90 | ·2414 | 4·14 | 257 |
| 92 | ·2456 | 4·07 | 253 |
| 94 | ·2499 | 4·00 | 249 |
| 96 | ·2543 | 3·93 | 245 |
| 98 | ·2586 | 3·86 | 241 |
| 100 | ·2628 | 3·80 | 237 |
| 105 | ·2738 | 3·65 | 227 |
| 110 | ·2845 | 3·51 | 219 |
| 115 | ·2955 | 3·38 | 211 |
| 120 | ·3060 | 3·27 | 203 |

When the ordinary evaporative performance of the fuel used in the boiler is known :—the quantity of water evaporated per pound of fuel, or the quantity of fuel required to evaporate a cubic foot of water—the average quantity of fuel consumed per mile is easily estimated, from the quantity of water consumed. The evaporative performance above defined is usually expressed in terms of the weight of water evaporated per pound of fuel. The volume of water, taken as cold water, in cubic feet per mile, may be multiplied by 62½, to give the weight of water in pounds; or the volume, if expressed in gallons, is to be multiplied by 10, to give the weight of water in pounds. The product so found is divided by the evaporative ratio of the fuel, and the quotient is the average quantity of fuel consumed per mile.

To exemplify the application of the foregoing rules, with the tables and the deductions, take the locomotives constructed by Messrs. Merryweather & Sons, at work on the tramways of Paris (Reseau Sud). The cylinders are 6 inches in diameter, with a stroke of 9 inches; the driving-wheels are 2 feet in diameter. The weight of the engine in full working condition is 4 tons, and it draws a loaded car, say, 7 tons in weight. The gross weight to be drawn is 11 tons; and the total resistance, on the level, at a uniform speed, at the rate of 30 lbs. per ton, is (11 × 30 =) 330 lbs. at the rail. To find the equivalent pressure on the pistons—the effective mean pressure, $p$, by formula (2):—

$$p = \frac{\mathrm{D}\ \mathrm{T}}{d^2\ \mathrm{L}} = \frac{24 \times 330}{36 \times 9} = 24{\cdot}4 \text{ lbs. per square inch.}$$

By the table, to produce an effective mean pressure of 24·4 lbs. per square inch, the initial pressures for different periods of admission, or cut-offs, are as follows:—

*For a Uniform Speed.*

| | | | | | Per square inch |
|---|---|---|---|---|---|
| Cutting off at | ⅕th, | the initial pressure is | 24·4 lbs. | × 3 | = 73 lbs. |
| Do. | ¼th | do. | 24·4 lbs. | × 2½ | = 61 lbs. |
| Do. | ⅓rd | do. | 24·4 lbs. | × 2 | = 49 lbs. |

For starting the train on the level, allow four times the tractive force, or four times the effective mean pressure required for a uniform speed—in this case, 1,320 lbs. traction, or 98 lbs. per square inch in the cylinders; then—

*For Starting the Train.*

| | | | Per square inch |
|---|---|---|---|
| Cutting off at ¾ | the initial pressure is | 98 lbs. × $\frac{10}{9}$ | = 109 lbs. |
| Do. ⅔ | do. | 98 lbs. × $\frac{5}{4}$ | = 122 lbs. |

If the pressure in the boiler be 120 lbs. per square inch, it is sufficient for the exertion of the extreme tractive forces above assumed.

But, suppose that the rate of the ruling gradient of the tramway amounts to 1 in 25. For the same tractional force, the gross load that can be taken up the line is, by the statement, page 357, reduced to one-fourth. To take up the same load, therefore, as on the level, the effective mean pressure in the cylinder should be four times as much as on the level, so that four times the tractive force may be exerted. That is, instead of an effective mean pressure of 24½ lbs. per square inch, there must be 98 lbs. effective pressure, being the same as was assumed for starting the train on a level. For the exertion of this pressure, it has already been shown, that the initial pressure in the cylinder would amount to 109 lbs. per square inch, supposing that the steam were admitted for three-fourths of the stroke, or to 122 lbs. for two-thirds of the stroke.

This example is sufficient to illustrate the wideness of the range of power that may be exerted by a tramway steam-locomotive.

To find, by formula (4), or (5), page 359, the average quantity of water actually consumed as steam per mile, supposing, as was assumed, that the average period of admission is half the stroke. To find, in the first place, the relative volume, which is a factor in the formula, the initial pressure in the cylinder is to be determined. For an effective mean pressure of 24½ lbs. per square inch, cutting off at half-stroke, the initial pressure is, by the table, page 355, (24½ lbs. × $\frac{3}{2}$=) 37 lbs. per square inch above the atmosphere. By formula (4) or (5), page 359, for which $d = 6$, $L = 9$, $D = 2$, and the relative volume of steam of 37 lbs. effective pressure, is 500:—

$$W = \frac{1{\cdot}71 \times 6^2 \times 9}{2 \times 500} = {\cdot}554 \text{ cubic feet};$$

$$\text{or } W = \frac{10{\cdot}7 \times 6^2 \times 9}{2 \times 500} = 3{\cdot}47 \text{ gallons}:$$

the average quantity of water consumed per mile.

To estimate, now, the quantity of fuel—which is coke—consumed per mile by Messrs. Merryweather's engine, it may be assumed, in the absence of positive data, that 7 pounds of water are evaporated per pound of coke. Reducing, then, the volume of water, ·554 cubic feet, or 3·47 gallons, to pounds, and dividing the weight by 7—

$${\cdot}554 \times 62\tfrac{1}{2} = 34{\cdot}35 \text{ pounds; and } \frac{34{\cdot}35}{7} = 5 \text{ lbs.}$$

$$\text{or } 3{\cdot}47 \times 10 = 34{\cdot}70 \text{ pounds; and } \frac{34{\cdot}70}{7} = 5 \text{ lbs.}$$

—showing a consumption of coke at the rate of 5 pounds per mile run by the engine, in drawing a gross load of 11 tons, including the weight of the engine. To this, of course, is to be added an allowance for getting up steam, and for contingent waste of steam and fuel—say 10 per cent: making an addition of ½ pound of coke per mile, and altogether 5½ pounds of coke consumed per mile.

Thus, by a simple process, founded on general experimental data, the exact quantity of coke actually consumed by those engines, as working on the Paris tramways, is arrived at. They consume 250 kilogrammes, or 550 pounds of coke for 100 miles run; which is equivalent to 5½ lbs. per mile, the same as has just been calculated.

The foregoing values for water and fuel give the following data :—

*Average Consumption per Ton Gross per Mile-Run.*

½ pound of coke.
3·5 pounds of water.

# CHAPTER III.

## HOT-WATER TRAMWAY-LOCOMOTIVES.

A BODY of water heated under pressure, spontaneously generates and disengages steam, when the pressure is permitted to fall. The temperature at the same time falls, according to the decline of the pressure; and the temperature and pressure correspond exactly as if steam were generated by the application of heat to the water under a given pressure.

The corresponding pressures and temperatures may be ascertained by referring to a table of the properties of saturated steam, and the quantity of steam that may be spontaneously generated during the fall of the temperature may be calculated with exactness. For example, suppose a pound of water, heated to the temperature 445° F., necessarily under the corresponding total pressure, 400 lbs. per square inch, and cooled to the temperature 281° F., corresponding to the total pressure, 50 lbs. per square inch.[1] The quantity of heat disengaged is measurable by the fall of temperature $(445° - 281° =)$ 164°, and for a pound of water the loss of heat is 164 units. The heat so disengaged is available for evaporating water—in fact, a portion of the heated water itself—into steam. Now, the total heats of the two steams are as follows:—

---

[1] See *A Manual of Rules, Tables, and Data*, 1877; page 387.

| Total pressure | Temperature | Total heat in 1 lb. of steam from 0° F. Units (or degrees) | Difference |
|---|---|---|---|
| 400 lbs. | 445° | 1,249 | 804° |
| 50 lbs. | 281° | 1,199 | 918° |
| (Mean) 225 lbs. | — | — | 861° |

The mean difference, or excess of heat in the steam above the sensible heat, is 861°, or 861 units for 1 pound of steam; and as the quantity of heat disengaged by 1 pound of water in falling from 445° to 281° is 164 units, there are required (861÷164=) 5·25 lbs. of the heated water to supply heat sufficient to evaporate 1 pound of the heated water. That is to say, out of 5·25 pounds of heated water, 1 pound is evaporated 'spontaneously.' In round numbers, one-fifth of the heated water is evaporated during the fall of temperature from 445° to 281°. By a similar calculation, it is found that the proportional quantities of heated water evaporated in falling to the temperature 281°, and total pressure 50 lbs. per square inch, from other temperatures and pressures, are as follows:—

*Falling to Total Final Pressure,* 50 *lbs. per square inch.*

| Total initial pressure in lbs. per square inch | Initial temperature | One pound of water evaporated in | |
|---|---|---|---|
| 400 lbs. | 445° | 5·25 | lbs. of heated water |
| 350 „ | 430° | 5·82 | „ |
| 300 „ | 418° | 6·35 | „ |
| 250 „ | 401° | 7·31 | „ |
| 200 „ | 382° | 8·74 | „ |
| 150 „ | 358° | 11·60 | „ |
| 100 „ | 328° | 19·20 | „ |

It may be said that, in round numbers, a fifth of the heated water is evaporated in falling from a total pressure of 400 lbs. per square inch to 50 lbs. per square inch, and that a ninth is evaporated in falling from 200 lbs. to 50 lbs. per square inch.

Without going further, it is obvious that between the limits of 400 lbs. and 200 lbs. initial pressure in the reservoir, worked down to 50 lbs., a quantity of water, in round numbers, from five to nine times the quantity of water that can be converted into steam, must be constantly carried on the engine:—a tax by which engines constructed on this principle—the principle of spontaneous evaporation—are unfitted for taking the place of ordinary steam-locomotives for work in the open air.

### Cockerell's Hot-Water Locomotive.

An instructive practical trial was made in June 1874, by the Société J. Cockerell, of Seraing, in Belgium, with one of their locomotives of the class designed for indoor service.[1] The boiler was vertical, 6½ feet high, and had two transverse water-tubes in the fire-box; the chimney rose direct from the fire-box, passing upwards through the steam-space. The boiler was not clad on the lower half of it, nor on the top, which was 3 feet in diameter. There were two cylinders, 8 inches in diameter, with a 10-inch stroke; four coupled wheels, 24 inches in diameter, 5 feet apart between centres, to a gauge of 4 feet 11 inches. The total capacity of the boiler was 35 cubic feet. The weight in working order was 8¾ tons; say, with four or five men, 9 tons.

---

[1] *Annales Industrielles,* February 7, 1875; col. 175.

*First experiment.*—The locomotive at rest in the open air. Twenty-five cubic feet of cold water was measured into the boiler. The fire was lit, and, in the course of 2¼ hours, steam was got up to 10 atmospheres effective. The water level rose 1·38 inches in the glass, corresponding to a dilatation of (1·38 × ·78 =) 1·076 cubic feet, or 1-33rd of the initial volume, passing from the temperature 54° F. to 365° F.

The fire was then extinguished, and the grate was withdrawn. The chimney was hermetically sealed at the upper end. The fire-door was simply closed; there was no closure for the ash-pan. The weather was fine, the temperature was 77° F. in the shade, and at 5 P.M. the locomotive was left to itself, when the initial effective pressure was 9·40 atmospheres.

COCKERELL'S HOT-WATER LOCOMOTIVE.

*Locomotive at Rest. Initial Effective Pressure* 9·40 *Atmospheres.*

| Time elapsed | | Fall of pressure | Fall of level |
|---|---|---|---|
| h. | m. | Atmospheres | Inches |
| 0 | 10 (5 P.M.) | 0·00 | 0·00 |
| 0 | 15 | 1·30 | 0·39 |
| 0 | 30 | 2·40 | 0·67 |
| 0 | 45 | 3·40 | 0·91 |
| 1 | 0 | 4·15 | 1·10 |
| 1 | 15 | 4·80 | 1·26 |
| 1 | 30 | 5·35 | 1·38 |
| 1 | 45 | 5·80 | 1·50 |
| 2 | 0 | 6·20 | 1·61 |
| 2 | 15 | 6·60 | 1·73 |
| 2 | 30 | 6·95 | 1·81 |
| 2 | 45 | 7·30 | 1·93 |
| 3 | 0 | 7·60 | 2·05 |
| 3 | 15 | 7·85 | 2·21 |
| 4 | 15 (9.15 P.M.) | 8·40 | 2·68 |
| 16 | 0 (9 A.M.) | 9·40 | 3·27 |

At the commencement of the observations, when the effective pressure was 9·40 atmospheres, the boiler contained 24·07 cubic feet of water as at 54° F. At the time of the last observation, when the pressure had fallen to atmospheric pressure, and the boiler was cool enough to permit of the hand being laid upon it, the quantity of water as at 54° F., contained in the boiler, only amounted to 22·54 cubic feet; showing an apparent loss of 1·53 cubic feet, in 16 hours, at joints or cocks, although no escape had been apparent. The provision against cooling was not considerable. The surface of the firebox in free contact with air, amounted to 49 square feet; that of the chimney 3⅓ square feet. It may be noted that whilst the pressure fell rapidly at the commencement, it fell less rapidly as it became lower.

*Second experiment.*—The locomotive, alone, was run to and fro upon a piece of railway 552 yards in length, consisting of two straight pieces connected by a slight curve. The line was nearly level; it had a slight gradient of about 1 in 400, at one end. It was in good order; but it contained several points and crossings.

Steam was got up to a pressure of upwards of 10 atmospheres effective, in 2½ hours after lighting the fire. The fire was then drawn, and the mouth of the chimney was hermetically sealed around the exhaust-pipe, which was prolonged upwards through the chimney. The circulation of cold air through the boiler was thus prevented. The fire-door was closed; but the ash-pan was left open. The cylinder-cocks were open for some time at starting, and the steam was cut off at 80 per cent. of the stroke.

During the journey, the steam was cut off at 60 or 70 per cent. During the last run, the maximum admission for steam was required, with the regulator wide open. Four or five men were carried on the engine.

There was a slight wind blowing, and to neutralise the circumstances of wind and gravity as far as possible, the engine was run to and fro several times. The effective pressure at the commencement amounted to 10·30 atmospheres; there was 24·91 cubic feet of water, as at 54° F., in the boiler; and of steam 10 cubic feet. At the end of the last return trip, the effective pressure was 1 atmosphere; there was 21·66 cubic feet of water, as at 54° F., and 13·29 cubic feet of steam. The total fall of pressure was, therefore, 9 atmospheres, and the quantity of water consumed was 3·25 cubic feet. The following are the results of the experiment:—

*Locomotive alone in Motion. Initial Effective Pressure,* 10·30 *Atmospheres.*

| Time elapsed | Total distance run | Average speed each trip | Fall of pressure |
|---|---|---|---|
| Minutes | Yards | Miles per hour | Atmospheres |
| 0 | 0 | 0 | 0·0 |
| 3 | 552 | 6·31 | 2·30 |
| 5 | 1,104 | 9·44 | 3·80 |
| 7 | 1,656 | 9·44 | 5·05 |
| 9 | 2,208 | 9·44 | 6·10 |
| 12 | 2,760 | 6·31 | 7·05 |
| 15 | 3,312 | 6·31 | 7·90 |
| 18 | 3,864 | 6·31 | 8·65 |
| 23 | 4,416 | 3·78 | 9·30 |

At the end of the last run, the engine was pushed home by two men for a few yards.

The total distance run was 2·51 miles, and the water consumed was at the rate of (3·25÷2·51=) 1·30 cubic feet, or 87 pounds, per mile. Allowing an evaporative power of 7 pounds of water per pound of fuel, the fuel consumed, if the steam had been generated on the journey, would have amounted to (87÷7=) 12½ pounds per mile; equivalent to (12½÷9=) 1·40 pounds per ton gross per mile.

It was observed that, though very little water or priming appeared with the exhaust-steam when the pressure was high, there was a notable increase of priming towards the end of the trial, when the pressure had fallen.

*Third experiment.*—The locomotive with one waggon was run to and fro on the experimental line. Immediately after the last experiment, steam was again got up in the engine. In 1 hour 10 minutes, an effective pressure of 10 atmospheres was got up; whilst the boiler was refilled. The fire was withdrawn, and the chimney was sealed, as before. An ordinary waggon, in ordinary condition, was coupled to the locomotive. The waggon had 4 wheels, 3 feet 3 inches in diameter, at 9 feet 9 inches apart between the axles. It was fitted with a screw-brake, and its weight with a small load was 8·80 tons. The gross weight drawn was as follows:—

| | Tons |
|---|---|
| Locomotive . . . . . . | 9 |
| Waggon . . . . . . | 8·80 |
| | 17·80 |

The initial effective pressure in the boiler was 10½ atmospheres, and the final pressure was 2·30 atmospheres. There were 24·91 cubic feet of water in the boiler at the commencement of the trial, and 21·91 cubic feet at the termination, after six trips were made; showing that 3 cubic feet of water was consumed on the trial.

*Locomotive and One Waggon in Motion. Initial Effective Pressure,* 10·50 *Atmospheres.*

| Time elapsed | Total distance run | Average speed, each trip | Fall of pressure |
|---|---|---|---|
| Minutes | Yards | Miles per hour | Atmospheres |
| 0 | 0 | 0 | 0 |
| 2·5 | 552 | 7·53 | 1·85 |
| 5 | 1,104 | 7·53 | 3·50 |
| 7·5 | 1,656 | 7·53 | 5·00 |
| 9·5 | 2,208 | 9·44 | 6·25 |
| 12·5 | 2,760 | 6·31 | 7·30 |
| 15·5 | 3,312 | 6·31 | 8·20 |

The total distance run was 1·90 miles, and the water was consumed at the rate of (3÷1·90=) 1·58 cubic feet, or 99 pounds per mile; or, calculating as before, 14 pounds of fuel per mile, equivalent to (14÷17·80=) 0·79 pound per ton gross per mile.

The performance of the engine was more economical in the last experiment; for the addition of the waggon caused but a small addition to the quantity of water consumed. The comparative economy of steam in the third experiment is due to the higher pressure necessarily employed in the cylinders to overcome the resistance of the greater weight to be drawn, and to the greater efficiency of the steam in consequence, against the constant resistance of the atmosphere. The following data are derived from the results of the third experiment:—

### HOT-WATER LOCOMOTIVE.

*Average Consumption per Ton Gross per Mile-Run.*

$\frac{4}{5}$ of pound of coke [in heating up the water].
$5\frac{1}{2}$ pounds of water.

The distance run for these rates of consumption was 2 miles, on a line of railway practically level.

These results do not compare advantageously with those of the Merryweather locomotive, page 365, where it appears that this engine on a tramway consumed only $\frac{1}{2}$ pound of coke per ton gross per mile, against the resistance of a tramway, and on inclines; whereas in the experiment with heated water, $\frac{4}{5}$ pound of coke is the equivalent of the quantity of water consumed on a railway nearly level.

# CHAPTER IV.

## COMPRESSED-AIR ENGINES.

COMPRESSED-AIR engines necessarily derive their power at second-hand; and they therefore work at a disadvantage, in point of efficiency, compared with steam-locomotives, in which the force is generated and expended simultaneously. A supply of air, previously compressed, is taken in by the propelling engine, and it is gradually dispensed to the working cylinders, where it works by expansion, and from which the force is transmitted to the driving-wheels by mechanism similar to that of a steam-locomotive. If the reverse actions—of compressing the air, and working it by expansion—could be made to take place between the same temperatures, pressures, and volumes, the work by expansion would be an exact duplicate, in reverse, of the work expended for compression; and the efficiency of the combined compressor and motor would be equal to 100 per cent., irrespective of losses by friction and clearance. But, under practical conditions, the initial temperature for expansion is not more than that of the surrounding atmosphere; and in working, by expansion, back to atmospheric pressure, even between the same extremes of pressure, the volumes are smaller, since the temperatures are lower. The efficiency must, therefore, be less than 100 per cent.

When air is compressed mechanically, the temperature is raised; and, if none of the heat so generated be permitted to escape, the air would be 'adiabatically' compressed. If air be subjected to compression, so that the pressure be doubled, trebled, &c., or so that, taking the initial pressure, at 62°, as 1,—
the relative pressures are as 2, 3, 4, 5, 10;
the final temperatures are, 178°, 258°, 321°, 373°, 559°.
It may be noted here, that, taking the initial temperature, 62°, as 1, the final temperatures are, very
roughly, as 3, 4, 5, 6, 9.

In practice, as was said, the air cannot be employed at these high temperatures. It is, in fact, cooled down by radiation and conduction, to the temperature of the surrounding atmosphere, before it is applied to do work. The loss of efficiency by the intermediate fall of the temperature of the compressed air from the absolute temperature $T,''$ due to the compression, to the absolute atmospheric temperature $T$, is simply the proportion which this fall $(T'' - T)$, bears to the higher temperature $T''$. It is so, because the volume is as the absolute temperature $T''$, and the loss of temperature $(T'' - T)$, indicates the loss of volume by contraction, under the same pressure. For instance, in compressing dry air at 62° to two atmospheres of pressure, in a non-conducting vessel, the temperature is raised to 178°, and the fall, in reverting to 62°, is $(178 - 62 =)$ 116°. The loss of efficiency due to this decline of temperature, is the proportion of 116° to (461° + 178° =) 639°, the maximum absolute temperature,[1] thus:—

(461 + 178 = ) 639°
(461 + 62 = ) 523°
Difference, or loss, 116° = 18 per cent. of the maximum absolute temperature.
Leaving 523° = 82 do. do. do.

The reduced efficiency here is 82 per cent. Take other examples:—

For ratios of pressure, or atmospheres,

2, 3, 4, 5, 10,

the final temperatures for compression are

178°, 258°, 321°, 373°, 559° F.;

and the losses of temperature, by the fall of the temperature to 62°, the initial temperature for expansion, are

116°, 196°, 259°, 311°, 497°;

whilst the reduced efficiency is

82, 73, 67, 63, 51 per cent.;

and the loss of efficiency is

18, 27, 33, 37, 49 per cent.

Thus, it is obvious that the lower the degree of compression applied to the air, the less is the rise of temperature, the less is the loss of heat by dissipation, and the greater is the efficiency of the machine.

---

[1] Absolute temperature is an expression signifying the measure of total heat in a body, as from the bottom of the scale of temperature. The zero of the scale of absolute temperature, or the point of no-heat, is 461 degrees below the zero point of the Fahrenheit scale; and to find the absolute temperature for any temperature indicated by the thermometer, 461° are added to the indicated temperature. For instance, the absolute temperature for 62° F. is (461 + 62 =) 523°.

As air under adiabatic compression may rise to temperatures which are impracticable, so air under adiabatic expansion—that is, expanded behind a piston, in a non-conducting cylinder—may fall to temperatures which are impracticable.

Thus, when the initial temperature is 62°, for ratios of adiabatic expansion,

2, 3, 4, 5, 10,

the final temperatures are,

−33°, −81°, −111°, −133°, −193°.

It is clearly as impracticable to work a compressed-air engine in such low temperatures, when every particle of moisture and lubricant would be frozen, as amongst the high temperatures previously noticed. Expedients are, therefore, needful for keeping the rise of temperature, during the compression of air, within feasible limits; and for limiting likewise the fall of temperature, during the expansion of compressed air. The former is effectively done by surrounding the compressing pumps with cold water, and by injecting cold water, in finely divided spray, into the mass of air whilst undergoing compression. Dr. Colladon has probably done more for the improvement and perfecting of air-compressing machinery than any other operator. In the air-compressing machinery at the works of the St. Gothard Tunnel, at Airolo, arranged by Dr. Colladon, it has been found by experiment that, by the means above indicated, the rise of temperature of air, even when the air is condensed under a pressure of ten atmospheres, was limited to from 36° to 54° Fahrenheit. The pistons had a stroke of 17·3 inches, and they made from 120 to 180 strokes per minute, giving speeds of piston of over 260 feet per minute. A quantity of cold water, equal in volume to 1-1000th of the volume of the stroke, was injected during each stroke.

The clearance space at each end of an air-compressing cylinder, affects very sensibly the yield, or *rendement*, of compressed air, by reducing it, to some extent, below the total volume of the stroke, or the space described by the piston for one stroke. This effect—the reduction of yield—is obviously due to the fact that the compressed air left in the clearance-space, after the stroke of the piston is completed, expands upon the piston as it recedes, and so far monopolises the cylinder, to the exclusion of a fresh supply of air, until its pressure falls, in due course, to an equality with that of the atmosphere. The reduction of yield, by this cause, increases as the pressure of compression is increased. In a series of observations made at Airolo, with the pumps already mentioned, having a stroke of 17·3 inches, with a clearance-space 1-80th of the volume of the stroke, making 64 turns per minute, the yield in weight of air was only 78 per cent., in compressing air in the reservoir, by the pump, from 6 atmospheres to 7 atmospheres. At higher pressures, the yield became still less, as follows:—

| Compression | Yield, in weight of air |
|---|---|
| From 6 to 7 atmospheres . . . . | 78 per cent. |
| „ 7 to 8 „ . . . . . | 74 „ |
| „ 8 to 9 „ . . . . . | 66 „ |
| „ 9 to 10 „ . . . . . | 59 „ |

In performing work with compressed air, on the contrary, accompanied by expansion, the fall of temperature is to be checked, that it may be prevented from falling to or below the freezing point. There is a well-known practical difficulty in working compressed air expansively. The extreme fall of temperature causes the freezing of moisture and the hardening of lubricants about the mechanism. For this reason, the working of air expansively is confined to narrow limits; and the air is admitted to the cylinder for nearly the whole of the stroke, that the cooling which results from expansion upon a piston may be reduced to a minimum. The most efficacious means of checking the fall of temperature, and mitigating the inconveniences of it, is to saturate the compressed air with moisture or vapour. According to the investigations of M. Mallard, the following are the ratios of expansion, to which dry air, and air saturated with vapour or moisture, respectively, may be worked before they fall to the temperature 32° F.

### EXPANSION OF AIR DRY AND MOIST.

| Temperatures | | Ratio of expansion | |
|---|---|---|---|
| Final | Initial | Dry air | Air with sufficient moisture or vapour |
| Fahr. | Fahr. | Ratio | Ratio |
| 32° | 40° | 1·05 | 1·10 |
| 32° | 50° | 1·13 | 1·24 |
| 32° | 60° | 1·22 | 1·38 |
| 32° | 62° | 1·23 | 1·41 |
| 32° | 68° | 1·28 | 1·50 |
| 32° | 70° | 1·30 | 1·56 |
| 32° | 80° | 1·37 | 1·75 |
| 32° | 90° | 1·47 | 2·00 |
| 32° | 100° | 1·57 | 2·28 |
| 32° | 110° | 1·67 | 2·63 |
| 32° | 120° | 1·76 | 3·00 |
| 32° | 130° | 1·88 | 3·45 |
| 32° | 140° | 2·00 | 4·00 |

As the steam is condensed during expansion, the heat that is liberated is absorbed by the air.

It was seen that when the compression of air was carried to 10 atmospheres, the efficiency for working in a compressed-air engine was only 51 per cent. Add, that the efficiencies of the machines themselves —the compressor and the power-engine—are factors for the calculation of their resultant efficiency, and if the efficiency of each machine be taken at 80 per cent., the combined percentage of the two machines is $\left(\frac{80 \times 80}{100} =\right)$ 64 per cent. or about two-thirds; and 64 per cent. of 51 per cent. is 33 per cent., the resultant efficiency of the combined compressor and engine, working to 10 atmospheres. Similarly, it is found that the resultant efficiency, working to 2 atmospheres, is 52 per cent. The less the degree of compression, the greater is the efficiency, because the less is the proportional loss from the intermediate reduction of temperature. In general practice, the resultant efficiency rarely exceeds 30 per cent. But, to give a character of precision to the relations of the first power and the final performance, the following are the resultant efficiencies, deduced from actual experiment, of 16-inch-cylinder air-compressing engines, and 10-inch-cylinder compressed-air engines, cutting off at 3-4ths, constructed by Messrs. John Fowler & Co. for Sir George Elliott—at work at Powell Duffryn Collieries. The air-cylinders were immersed each in a cold-water bath, open at the upper side. The resultant efficiency is here expressed by the ratio of the brake-power of the compressed-air engine to the indicator-power in the steam-cylinder of the air-compressing engine[1]:—

Effective pressure of air in receiver:—

40·0, 34·0, 28·5, 24, 19 lbs. per square inch.

Indicator horse-power in the steam-cylinder:—

59·4, 46·2, 35·8, 25·8, 11·8 I.H.P.

Resultant efficiency:—

25·8, 27·1, 28·5, 34·9, 45·8 per cent.

### Compressed-air Tramway-car, by M. Mékarski.

Early in 1876, a tramway-car, propelled by compressed air, was constructed by M. Mékarski, and tried on the Courbevoie line of the Tramway Nord, in Paris. The car is, in general outline, on the model of the cars of the Compagnie des Tramways. The body is 11½ feet long, and accommodates 20 passengers inside; there is also room for fourteen passengers outside, on a spacious platform at the rear. Compressed air, of 25 atmospheres, is stored in eight cylindrical reservoirs of plate-iron, from 12 to 16 inches in diameter, placed transversely underneath the carriage, and connected together. They are in two separate series. The capacity of the principal series is 52 cubic feet, and that of the second, or reserve, series, is 17 cubic feet. An upright reservoir, 14 inches in diameter and about 5 feet in height, is placed at the fore end of the car, is three-fourths filled with water heated to 340° F., corresponding to a pressure of 103 lbs. per square inch above the atmosphere. The compressed air, as drawn off for consumption, is passed through this reservoir, in which it becomes saturated with vapour. The mixture of air and water occupies the upper part of the reservoir. The frame of the car is of wrought iron, 5 feet 10 inches wide, and 18 feet 8 inches long. The car runs on two pairs of wheels about 28 inches in diameter, and placed 6 feet 10 inches apart. One pair of the wheels is driven by a pair of cylinders, 5 or 6 inches in diameter, with about 10 inches of stroke. The weight of the car is $4\frac{3}{4}$ tons, and with a load of 30 passengers the weight is 7 tons.

---

[1] The substance of this chapter on the principles and the action of compressed-air motors is derived from the author's work *A Manual of Rules, Tables, and Data*, 1877; pages 898–914.

The air is wire-drawn to a pressure of 5 atmospheres for working in the cylinders. M. Mékarski calculates that the fall of pressure by wire-drawing, from 25 atmospheres to 5 atmospheres, followed by the complete expansion on a piston from 5 atmospheres down to atmospheric pressure, results in an efficiency of 62 per cent.—that is to say, a loss of 38 per cent.; and that this loss is compensated by the re-heating of the air during expansion by the intermixed steam. The expenditure in thus re-heating the air is only a small proportion of the total fuel consumed. The quantity of heated water supplied to the reservoir of the car is about 3 cubic feet, at a temperature of 340° F., and the car returns with about $2\frac{2}{3}$ cubic feet of water at 212° F., the difference representing the consumption of about 2 pounds of coal, whilst the fuel consumed in charging the reservoirs with compressed air amounts to 33 pounds of coal. The cooling of the heated water, and the diminution of pressure of the air in the reservoir, take place simultaneously in the course of the journey; and thus the elements of the mixture may be maintained in sensibly constant proportions. It is stated that the quantity of air consumed does not exceed 11 cubic feet per mile run.

The Mékarski car works well as a mechanical engine—free from smoke, steam, noise, and fumes. But it does not appear that the cost of working the car is generally known.

### COMPRESSED-AIR TRAMWAY-CAR, BY MR. SCOTT-MONCRIEFF.

Mr. Scott-Moncrieff's car, worked by compressed air, resembles in appearance an ordinary tramway-car. The reservoirs and machinery are carried on a frame below the floor of the car. In the central portion the engines are carried. In the car first made, and started for trial, about the middle of 1875, on the Vale of Clyde Tramway, there were six reservoirs holding compressed air—three at each end of the car. The air was supplied to the reservoirs at a pressure of 350 lbs. per square inch. There were two air-cylinders, 6 inches in diameter, with a stroke of 14 inches. The supply of air was wire-drawn before it was admitted into the cylinders, and cut off so that it expanded to, and was exhausted at atmospheric pressure. The total weight of the car was 6¾ tons; with 40 passengers, 10½ tons. Mr. Scott-Moncrieff states, that during a trial of the car, lasting fourteen days, on the line between Govan and Paisley Toll, the reservoirs were charged, after every three miles-run, with compressed air, having a pressure of 310 lbs. per square inch, which was worked until the pressure fell to 100 lbs. or 110 lbs. The average pressure in the cylinders was about 22½ lbs. per square inch. Mr. Scott-Moncrieff states that his car consumed from 400 to 500 cubic feet of air as at atmospheric pressure per mile, and he is of opinion that a compressing-engine of about 150 indicator horse-power would be capable of keeping up a service of 1,000 miles per day.

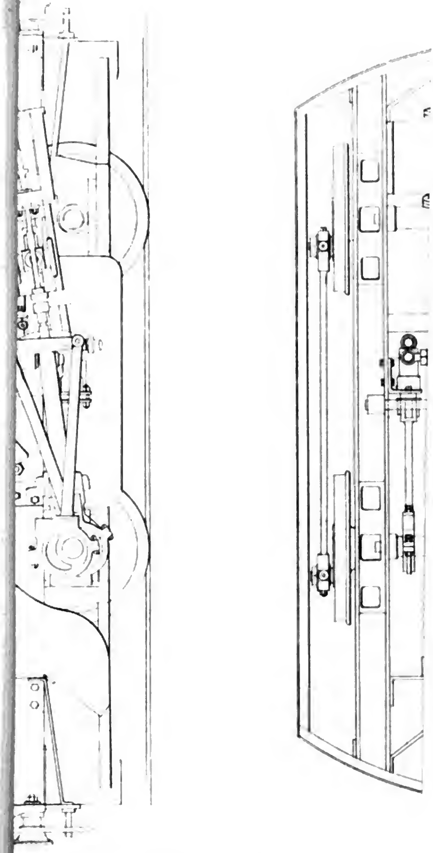
Mr. Scott-Moncrieff's engine resumed regular duty on the Vale of Clyde for a few weeks in the beginning of 1877. From the results of his experiments, he concluded that the cost price of working —including drivers' wages, lighting, cleaning—was between 3*d.* and 4*d.* per mile run.

### MAJOR BEAUMONT'S COMPRESSED-AIR CAR.

Messrs. Greenwood & Batley are engaged in the construction of Major Beaumont's compressed-air car. The initial pressure in the reservoirs, which have a capacity of 65 cubic feet, is 1,000 lbs. per square inch. This high pressure is adopted, for the constructors found that the higher the pressure the greater was the efficiency. This conclusion is apparently in contradiction to the conclusions drawn from other experience, as well as from the elementary data which have already been considered. But the explanation lies in the use of a compound-engine of four cylinders, in which the air is successively expanded down from an initial pressure of 1,000 lbs. per square inch, to the pressure at which the air is exhausted into the atmosphere. The volumes of the cylinders successively are as 1, 3, 9, 27, having a common ratio of 1 to 3, and showing that the air may be expanded in the engine as many as 27 times. When the pressure falls off, the first cylinder is closed to the air, which is then turned on direct to the second cylinder; again, on further need, it is closed to the second cylinder, and turned on direct to the third, and ultimately direct to the fourth. As Mr. Greenwood remarks, the same power may thus be got out of the engine under a decreasing pressure. He calculated on a loss of four-fifths of the steam-power used for compression; but he hopes to reduce the loss to two-thirds, leaving one-third of the work of the steam as the useful work done. The horse-power given out per cubic foot of air at 1,000 lbs. pressure is under 5 horse-power. The engine above noticed has run 6½ miles with a load of 4 or 5 tons; but Mr. Greenwood considers that with a reservoir of 100 cubic feet of capacity, fully charged, a run of ten miles could be made. The weight of such an engine would be from 4 to 4½ tons.

## OMOTIVE BY MESSRS MERRYWEATHER &

CYLINDERS 7 IN × 11 IN WHEELS 2 FT GUAGE 4 FT 8½ INS.



SCALE [illegible] FULL SIZE

wood and Co 7, Stationers' Hall Court, London

# CHAPTER V.

## TRAMWAY LOCOMOTIVES, BY MESSRS. MERRYWEATHER AND SONS, LONDON.

PLATES X., XI.

MESSRS. MERRYWEATHER & SONS construct three classes of steam locomotives for tramways :—

1. Cylinders, 6 inches diameter; stroke, 9 inches; wheels, 2 feet. Weight, empty, 3¼ tons; in working order, 4 tons.

2. Cylinders, 7 inches diameter; stroke, 11 inches; wheels, 2 feet. Weight, empty, 5·4 tons; in working order, 6 to 6½ tons.

3. Cylinders, 7½ inches diameter; stroke, 12 inches; wheels, 2 feet. Weight, empty, 6½ tons; in working order, 7½ to 8 tons.

The working pressure in the boiler is 8 atmospheres, or nominally 120 lbs. per square inch. The guaranteed maximum performances are respectively as follows :—

1. To draw 1 loaded car, weighing 7 tons, up an incline of 1 in 30.

2. To draw 1 loaded car, weighing 7 tons, up an incline of 1 in 18; or 2 loaded cars, weighing 14 tons, up an incline of 1 in 30.

3. To draw 2 loaded cars, weighing 14 tons, up an incline of 1 in 16; or 3 loaded cars, weighing 21 tons, up an incline of 1 in 20.

Engines of the third class have taken three cars up an incline of 1 in 18, at regular work.

---

### PARIS.

The tramway locomotives of Messrs. Merryweather & Sons, now at work on the Southern Tramways of Paris, thirty-six in number, have, as already mentioned, two cylinders, 6 inches in diameter, with a stroke of 9 inches. The cylinders are horizontal, inside the framing, and connected to cranks on the driving-axle. There are two pairs of driving-wheels of cast steel, coupled, 2 feet in diameter, 4 feet 7 inches apart between centres of axles. The blast-orifice is annular in form, and has an area of 1 square inch, being about 1-28th of the area of the pistons. The length of the frame is about 8 feet, and the width is 6 feet. Over the buffers, which are central, the extreme length is about 8 feet 10 inches. The load is carried by a pair of helical springs over each journal. The buffing and draw-springs, of indiarubber, at each end, are well connected to the frame, the attachment having been taken as near to the centre of the machine as was conveniently practicable. A close-laid draw-pin eases the traction very much, compared with a distant draw-pin. The engine is braked by cast-iron blocks, applied one to each wheel. The whole machine is enclosed into a large wooden box, made like a short tramway-car, having several windows. The fire-box is 2 feet wide, and 1 foot 6 inches long. The barrel of the boiler is 2 feet 9 inches long, and 2 feet 3 inches in diameter; it contains 65 flue-tubes, 1¼ inches in diameter, and 3 feet long:—

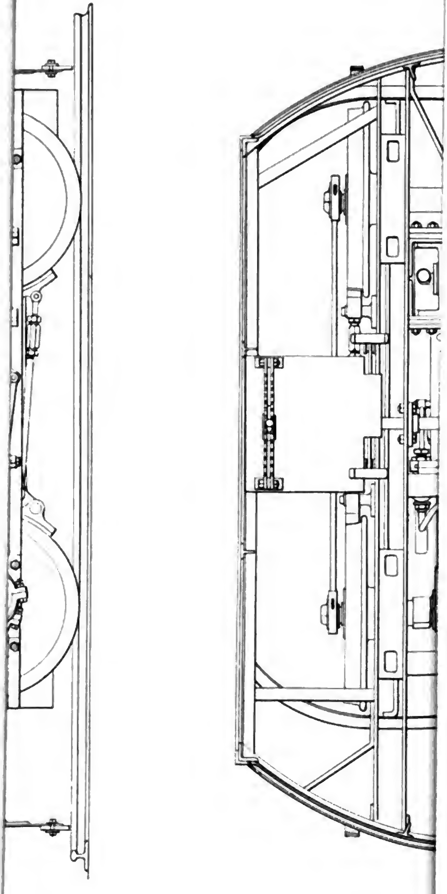
| | Square feet |
|---|---|
| Heating surface in fire-box | 16·0 |
| Do. do. tubes | 89·3 |
| Total | 105·3 |
| Area of fire-grate | 3 |

Ratio of grate to heating surface, 1 to 35.

The pressure in the boiler is nominally 8 atmospheres, or 120 lbs. per square inch; but the working pressure usually maintained is 6 atmospheres, or 90 lbs. per square inch. The steam is cut off in the cylinders at from 1-4th to 3-4ths of the stroke. The length of the journey is 4 miles, between the Bastille and the Gare de Mont Parnasse, on which the maximum incline has a gradient of 1 in 50, whilst there are long inclines of from 1 in 60 to 1 in 70. The speed is limited by law to 9 kilometres, or a little over 5½ miles per hour; but it occasionally rises to 14 or 15 miles per hour, and the average speed, including stoppages, is 8½ miles per hour. The weight of the engine, empty, is 3¼ tons; with coke and water, 4 tons. It draws a car which, when loaded, weighs 7 tons; and it can ascend the inclines with its load, and keep time, with a pressure in the boiler of 90 lbs. per square inch. The fuel (coke) consumed per day, amounts to 550 lbs. for a total distance run of 100 miles:—at the rate of 5½ lbs. per mile. The combustion of the fuel proceeds at a comparatively low rate. Supposing that the average actual speed while running is 10 miles per hour, the quantity of coke consumed per hour would be (10 × 5·5 =), 55 pounds, equivalent to (55 ÷ 3 =) 18⅓ pounds per square foot of grate. In the ordinary practice of locomotives on railways, the quantity of fuel consumed per square foot of grate per hour amounts to three or four times as much. The comparatively low rate in the Merryweather engine, is easily accounted for by the comparatively low speed, and the reduced blast and draft which are required for the generation of steam. It is true, the area of the blast-orifice is contracted to 1-28th of that of the pistons, which is a very small fraction, and would cause great back-pressure on the pistons if the engine travelled at a high speed. But it is to be observed that the pistons travel at a comparatively low speed. The wheels, 2 feet in diameter, and 6·28 feet in circumference, make (5280 ÷ 6·28 =) 841 turns in a mile, or in (60 ÷ 10 =) six minutes of time, when the speed is 10 miles per hour. The number of turns per minute is, then (841 ÷ 6 =) 140; and, as the double stroke of the piston is (9 × 2 =) 18 inches, or 1·5 feet, the speed of the pistons is only (140 × 1·5 =) 210 feet per minute.

The engines, more recently constructed, for the tramway from the Bastille to St. Mandé, illustrated in Plate X., are more powerful than those just described. They have 7-inch cylinders, with a stroke of 11 inches, and 2-feet wheels. The firebox is 2 feet 2 inches by 2 feet, having an area of 4·33 square feet of grate. The firebox-surface is 24·5 square feet; there are 79 flue-tubes, 1¾ inches in diameter outside, and 3 feet 6 inches long, giving 126·6 square feet of heating surface. The total heating surface is 151·1 square feet, and it amounts to 35 times the area of grate. The diameter of the barrel of the boiler is 2 feet 6 inches; the length of

YWEATHER AND SONS.
T GUAGE I METRE



ZE.

Hall Court. London

the engine, over all, is 6 feet 7 inches, and the length of the wheel-base is 4 feet 6 inches. The form of the tyre of the wheels is shown in section, fig. 98, page 188.

Additional engines of equal power are in course of construction for other lines of tramway in Paris, to work the increased traffic consequent upon the approaching Exhibition.

The conditions under which the Merryweather engine at Paris is worked, taken together, are favourable for its durability and economical maintenance.

### BARCELONA.

The locomotives constructed for the tramway from Barcelona to St. Andrès, on a 1-metre gauge, illustrated by Plate XI., have 6-inch cylinders, with a stroke of 9 inches, and four 2-feet wheels, coupled. The fire-grate has 3 square feet of area. The barrel of the boiler is 27 inches in diameter; and there are 96 flue-tubes, 1⅜ inches in diameter, and 3 feet in length. The heating surface of the fire-box is 16 square feet, of the tubes 102·7 square feet, total surface 118·7 square feet. A tank to hold a supply of cold water, 300 gallons, for condensing the steam, is placed overhead. The exhaust-steam is discharged from the cylinders into an apparatus like an ejector, in the lower part of the engine, to which the water is conducted from the tank, where it meets and condenses the exhaust-steam, and whence it returns by a return-pipe to the tank. The water, of course, becomes gradually heated, but the condensation of the steam is effective, and there is no appearance of escaping steam, until the temperature of the water arrives near the boiling point. Possessing so wide a range of effective action, a tankful of cold water lasts good, for condensing the exhaust-steam, for two hours, over a distance of more than 10 miles. The distance to be run before the water can be heated, from, say, 62° F. to, say, 180° F., is easily determined. The quantity of fuel consumed per mile is 5 pounds, evaporating, say, 7 pounds of water per pound of fuel, the quantity of steam generated per mile would be $(5 \times 7 =)$ 35 pounds, exhausted at, say, a pressure of 3 lbs. per square inch. The total heat of one pound of steam of 3 lbs. effective pressure per square inch, is 1117 units, reckoned from a temperature of 62° F., or 967 units, reckoned from 212°. The mean total heat per pound of steam to be extracted by condensation is $((1117 + 967) \div 2 =)$ 1042 units. Each pound of condensing water absorbs $(180 - 62 =)$ 118 units of heat, when heated from 62° to 180°; and, to condense 1 pound of steam, the quantity of water required is $(1042 \div 118 =)$ 8·8 pounds. The total weight of water in the tank is (300 gallons $\times 10 =)$ 3000 pounds; and $(3000 \div 8{\cdot}8 =)$ 341 pounds of steam, is the total quantity that may be condensed by the store of condensing water. As 35 pounds of steam is consumed per mile, the supply of condensing water would last for $(341 \div 35 =)$ 10 miles, equivalent to 30 gallons per mile:—a result of calculation which agrees with the results of practice.

For occasional use, a blast-pipe is adopted for exhausting the steam into the chimney; it is fitted with the means of contracting the area of the orifice, by a conical plug with a rack-and-pinion movement.

A steam-jet is also available at will, by a nozzle placed concentrically within the blast-pipe. Two truncated cones are placed one above the other, over the blast-pipe and below the chimney, through which the blast is directed upwards. They are useful in inducing the draft from the lower rows of flue-tubes, as well as from the upper rows; and they assist the absorption of the exhaust-steam by the hot air, whereby, except in very cold weather, it issues from the chimney invisible: so far dispensing with the use of the water-condenser.

The Barcelona Tramway was opened in November 1877. The engines each take two loaded cars up inclines of 1 in 30. The traffic has so rapidly increased that the additional engines to be supplied by the same makers will have cylinders 7 inches in diameter, of the same power as the later engines constructed for the Paris tramways.

## CASSEL, ROUEN, GUERNSEY, AND WELLINGTON, NEW ZEALAND.

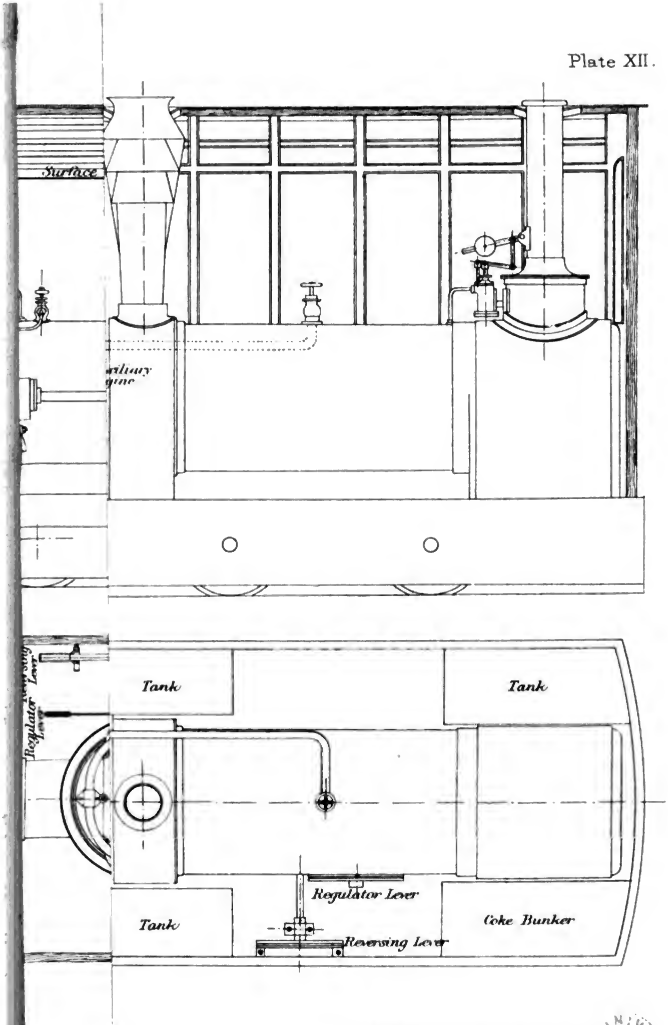
The engines of the Cassel Tramway, which was noticed at page 188, opened in August 1877, were supplied by Messrs. Merryweather & Sons. They were constructed with 7½-inch cylinders, having 12 inches of stroke. They draw three loaded cars over the road, on which the inclines are severe, some of them equal to 1 in 16.

Engines by the same constructors are at work on the Rouen Tramway, which was opened in November 1877. The cylinders are 6 inches in diameter, with a stroke of 9 inches. The engines work one large loaded car up inclines of 1 in 25.

In Guernsey, the Royal Court, in December 1877, granted permission for the construction of tramways to be worked by steam power. The works are now (February 1878) in course of construction; and one of Messrs. Merryweather's engines has been working on the portion already completed. Additional engines by the same makers are being constructed for this tramway.

The first tramways in New Zealand have recently (February 1878) been opened at Wellington; already noticed, page 190. The locomotives, supplied by Messrs. Merryweather & Sons, have 7-inch cylinders, with an 11-inch stroke. The gauge is 3 feet 6 inches. A rapid extension of tramways is expected throughout the Colonies.

Plate XII.



Thomas Kell, Lith 40, King Street, Covent Garden

UNIV. OF MICH.

## CHAPTER VI.

### AUXILIARY COMPOUND INCLINE-LOCOMOTIVE FOR TRAMWAYS. BY MR. HENRY P. HOLT.

PLATE XII.

MR. H. P. HOLT has comprehended in his incline-locomotive for tramways, a short wheel-base, and comparatively light weight, for the maximum power which the engine is capable of exerting. The cylinders, two in number, as usual, are arranged as compound-cylinders:—a smaller cylinder worked by steam at high pressure direct from the boiler; and a larger cylinder, worked by steam at lower pressure exhausted from the smaller cylinder. There are two regulators, one above each cylinder, controlled by a single lever, and so arranged that, for starting the engine, or on any other occasion when the full power of the engine is required to be exerted, steam of high pressure from the boiler may be supplied direct into the second or larger cylinder, as well as into the first or smaller cylinder;—the exhaust steam from each cylinder being delivered direct into the chimney, or the condenser, as the case may be.

In the normal condition, when the engine works as a compound-engine, the steam admitted to the first cylinder is partially expanded there, and is exhausted into an intermediate receiver, which is formed of three large tubes lodged within the boiler. There, it is in some degree superheated, or reheated, and thence it passes to the second cylinder, where it is further expanded against the piston, and whence it is exhausted into the chimney, or into a condenser.

The supply of steam to the first and the second cylinders respectively, may be adjusted by means of the compound regulator already mentioned, according to the position of the lever. In the first half of its range, steam is supplied at full pressure to both cylinders, when the lever is in the extreme position; and the supply to the second cylinder is gradually reduced until, when the lever is mid-way, the supply from the boiler is shut off altogether from the second cylinder, whilst it is continued in undiminished quantity to the first cylinder. The second cylinder, of course, continues to draw steam from the receiver. In the second half of the range of the lever, the supply to the first cylinder is gradually reduced, until the steam is entirely shut off, when the lever is at the other end of its range. When steam is supplied only to the first cylinder, the supply from the receiver to the second cylinder is so regulated that there may be little or no drop of pressure, as between the two cylinders.

There are two reversing levers, which may be moved together, or notched up separately, in order to vary the cut-off separately in the two cylinders. By means of a catch, the high-pressure lever is moved and dropped into the position for full gear, whenever the low-pressure lever is thrown into full gear.

An addition to the tractive power of the locomotive is made, without materially increasing the weight, by the addition of a small auxiliary high-speed single-cylinder steam-engine, employed to drive the wheels of the following car: thus utilising the weight of the car for adhesion. The motion of the engine is communicated to the car-wheels by means of a coupling chain, which passes over chain-pulleys fixed on the shaft of the engine and the axles of the car. The car is uncoupled from the engine by slipping the chain off the pulleys.

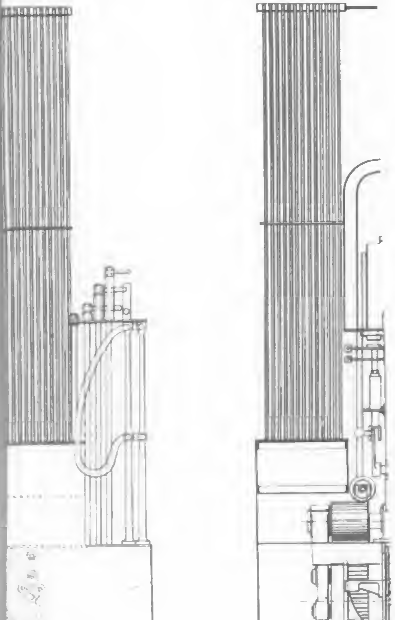
The locomotive and the car are coupled together, and kept at a regular distance apart, with an adjustable spring-buffer. There is a self-acting motion whereby the brakes of the car are applied when the engine and the car approach each other within less than the normal distance apart. There is a brake also on the engine, which, to avoid complication, is omitted from the plans.

To prevent steam from blowing-off at the safety-valves, the heat in the firebox is reduced by the escape of a portion of the gases from the firebox direct to the chimney. The escape is provided for by a flue, constructed in the crown of the firebox, fitted with a damper, which is opened and closed according as the pressure of the steam in the boiler rises and falls. This damper is self-acting; and is controlled by a piston which works in a small cylinder open to the pressure of the steam in the boiler; and is moved to or fro, according as pressure rises above or below the normal force.

The draught through the tubes is equalised by the application of a series of taper nozzles, having the form of truncated cones, placed vertically in the smoke-box, in front of the tube-plate. Each nozzle draws the gaseous products from the flue-tubes nearest to it. The exhaust-steam is discharged upwards through the nozzles into the chimney; and it becomes intimately mixed with the gases which are drawn into the current by induction, at the various levels; and is thus rendered entirely, or for the most part, invisible. At the same time, since the generation of excessive local draughts through the tubes is prevented, there is a much less proportion of dust drawn into and ejected from the chimney. Induction-nozzles are employed also in the chimney, in order still further to intermix the gaseous products with the steam.

To prevent the appearance of steam from the chimney when the engine is started, as well as to render noiseless the beats of the exhaust, the steam is exhausted into a receiver, the pressure in which is maintained nearly constant by means of a self-adjusting exhaust-nozzle. The opening of the nozzle is adjusted to the quantity of steam which passes; when the pressure falls, or when the engine is stopped, the nozzle is closed automatically, and shuts-off the exhaust, until exhaust-steam is again discharged, and the pressure rises in the exhaust-receiver.

LOCOMOTIVE, BY Mr LOFTUS PERKIN



CALE $\frac{1}{24}$th FULL SIZE

and C°, Stationers Hall Court London

# CHAPTER VII.

## TRAMWAY-CONDENSING LOCOMOTIVE, BY MR. LOFTUS PERKINS, LONDON.

PLATE XIII.

MR. PERKINS has availed himself of the results of his experience with the locomotive at Brussels, already noticed, page 328, in the design of the condensing locomotive, Plate XIII. It is compactly arranged, within a length of 10 feet, a width of 7 feet, and a height of 9 feet 8 inches above the level of the rails, exclusive of the chimney, which is about 13 or 14 feet high. The wheel-base is 4 feet 3 inches in length, and the width of gauge is 4 feet 8½ inches. The boiler and the engines are placed side by side in the middle, and they are flanked by two air-condensers. The motion is reduced by toothed gearing from the crank-shaft to an intermediate shaft, and is thence communicated to all the wheels by coupling-rods.

The boiler is vertical, and is constructed on Mr. Perkins' water-tube system. There are nine tiers of wrought-iron tubes, bent to an oblong form, with circular ends, 2¼ inches in bore, and ⅜ inch thick. The tiers are connected vertically by short junction tubes of smaller diameter. The boiler is 'absolutely safe from explosion.' The total external heating surface presented is 90 square feet. The area of grate-surface is 3 square feet. Thus the ratio of the fire-grate area to the heating surface is 1 to 30. The pressure of steam in the boiler is 500 lbs. per square inch, though the boiler is constructed to bear a maximum pressure of 800 lbs. per square inch. The chimney is sufficient, by the natural draught, for the production of steam, with coke as fuel.

The engine consists of two single-acting cylinders and one double-acting cylinder. The single-acting cylinders have one piston-rod; the steam, at 400 lbs. pressure, being admitted above the piston by the first and smallest cylinder, 3⅛ inches in diameter; then expanded into the second, or medium, cylinder, 5½ inches in diameter, below its piston; lastly, exhausted into the double-acting cylinder, which is 7½ inches in diameter. The first and second cylinders thus work together as one cylinder, and they, with the third cylinder, are connected to a crank-shaft, with a stroke of 9 inches. The object of the combination of the first and second cylinders, and working them by single action, is to prevent the exposure of the packing round the piston-rod to the extreme temperature of the steam as first admitted. The steam is cut off in the first cylinder at three-fourths of the stroke; and whilst its initial temperature at 400 lbs. effective pressure is about 450° F., the pressure falls by expansion to something less than 300 lbs. effective pressure when the steam enters the second cylinder, where the initial temperature does not exceed 420° F. A sufficiently high degree of expansion is obtained by this combination, for the working volumes of the cylinders are as follows :—

| | | Area of piston | |
|---|---|---|---|
| 1st cylinder | . . . . | 7·67, | as 1 |
| 2nd do. | . . . . | 23·76, | as 3·23 |
| 3rd do. | 44·18 sq. in. × 2 = | 88·36, | as 11·52 |

Setting off the expansion in the first cylinder against the reduction of expansive action by clearances, it may be taken that the steam may be finally expanded to twelve times its initial volume before being exhausted into the condensers. The cylinders are jacketed with steam direct from the boiler; the jackets are in reality coils of pipes, of small bore, conducted round the cylinders, embedded in the castings. The engine, boiler, and chimney are entirely enveloped in a non-conducting casing of vegetable-black, 3 inches thick.

The condensers consist each of a great number of brass tubes, $\frac{1}{2}$ inch in diameter outside, and 6 feet long, placed vertically on a hollow base, and pitched at a distance of one inch between centres. The steam is exhausted into the hollow base of each condenser, whence it freely enters the tubes, which are nearly closed at the upper ends, leaving only a very small opening, $\frac{1}{16}$ inch in diameter, to the atmosphere. They present an area of external surface equal to 1,500 square feet, of which, it is stated, 150 square feet are sufficient for the formation of one cubic foot of water per hour, by the condensation of steam as from a temperature of 212° F., or atmospheric pressure. The total quantity of steam that could be condensed per hour, as from 212° F., would thus amount to 10 cubic feet of water, which affords ample margin. The feed is drawn from the condensation-water. The temperature of the condensation is from 210° to 212° after the water-supply is heated. The back pressure in the condenser is about 1½ lbs. per square inch above the atmosphere.

The intermediate shaft is geared to the crank-shaft in the ratio of 4 to 1, to make one turn for four of the crank-shaft, and the motion is transmitted by 4-inch cranks, with coupling-rods, to the wheels, which are 24 inches in diameter. The play of the springs is allowed for by a slot in each coupling-rod. The axle-boxes of each pair of wheels are united into one piece, reaching across the engine.

The weight of the locomotive, empty, is 5½ tons, of which 10 cwt. is contributed by the condensers. The weight, in full working order, with fuel and water for the day's work, is 6 tons.

It is anticipated that very economical results of performance will be obtained by the use of this locomotive. In a stationary engine and boiler constructed on the same system, 18-indicator horse-power has been realised with a consumption of 30 pounds of coke per hour, equivalent to 1·67 pounds per horse-power per hour. The waste of water in the engine is only 5 gallons in 12 hours.

The tramway locomotive, working at full power, will, it is stated, indicate 30 horse-power, with a consumption of about 50 lbs. of coke per hour, or 17 lbs. per square foot of grate per hour. The Perkins locomotive for tramways is manufactured by Messrs. Greenwood & Batley, Leeds.

# CHAPTER VIII.

## BISSELL-BOGIE STEAM-CAR, BY MR. EDWARD PERRETT, LONDON.

Mr. **Edward Perrett** has arranged a steam-car, figs. 121, 122, in which the machinery is placed horizontally under the frame, and two vertical steam-boilers are placed on the platform, one at each end of the car, and connected together. The weight is thus equally distributed, and the car is run either end foremost. The car runs on eight wheels, and weighs 8 tons when loaded, of which 5 tons rest on the four middle wheels, which are driven by the engine, and 3 tons is divided between the fore pair and aft pair of wheels. These wheels, fore and aft, are arranged as Bissell trucks, radiating outwards on pivots, and they are controlled at either end by steering gear, so that the car may be taken with facility off the road, on to a branch, or *vice versâ*. The fixed wheel-base—that of the driving-wheels—is 4 feet, and the total wheel-base is 17 feet. The two cylinders are 6 inches in diameter, with a stroke of 9 inches; the coupled driving-wheels are 27 inches in diameter, and the bogie-wheels are 18 inches. The steam-boilers, on Broadbent's system, are 25½ inches in diameter outside, and 6 feet long;

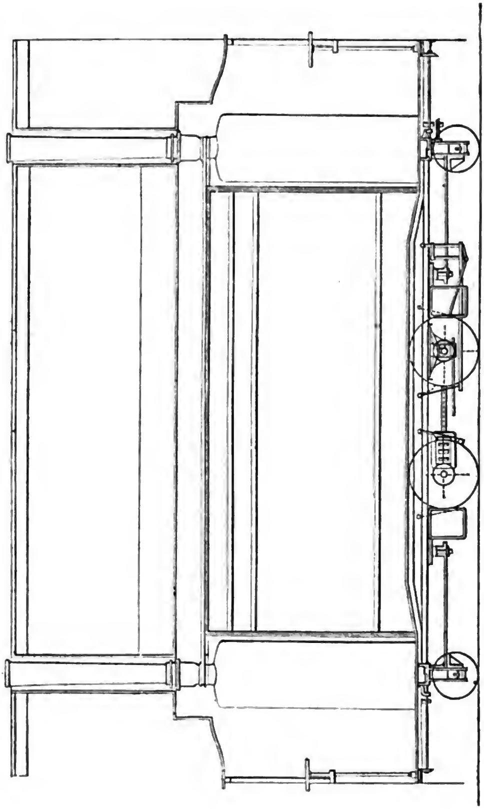


FIG. 121. Bissell-Bogie Steam-car, by Mr. Edward Perrett, 1876. Scale, $\frac{1}{48}$.

the firebox is 20½ inches in diameter at the grate, giving 2·27 square feet of grate-area for each boiler.

An experimental steam-car was constructed on this system, with 5-inch cylinders, and an 8-inch stroke; 27-inch driving-wheels at 4-feet centres, and 19-inch bogie-wheels, at 14-feet centres; 1·60 square feet of grate for each boiler; total weight 8 tons, of which 5 tons was driving weight. It was publicly tried in May 1876; and it is reported that the car ran easily on a circular line of 35 feet radius, to a gauge of 4 feet 8½ inches, with a pressure of 90 lbs. per square inch in the boiler, cutting off at 5-8ths of the stroke; though it was necessary to get up the pressure to 120 lbs. per square inch before starting again. With a pressure of 120 lbs., the car could start on an incline of 1 in 30.

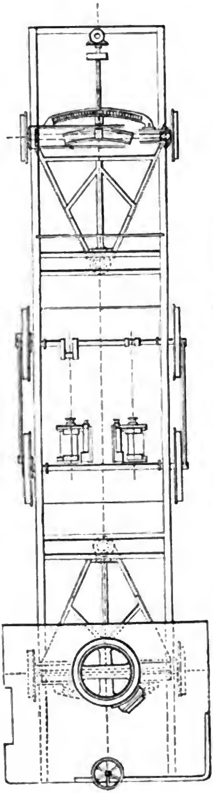


Fig. 122. Mr. Perrett's Steam-car. Plan. Scale, $\frac{1}{48}$.

# CHAPTER IX.

## DOUBLE-BOGIE STEAM-CAR, BY MR. A. BROWN, WINTERTHUR.

Mr. A. Brown, of Winterthur (Switzerland), designed a steam-car for tramways. on the principle of Mr. R. F. Fairlie's double-bogie railway steam-carriage. An illustration of his original design was published in 'Engineering,' for March 31, 1876. He constructed a steam-car on the same system, on a somewhat modified design, which was put to work, in 1877, on the Lausanne and Echellens Branch Railway —a 'Chemin de Fer Régional'—for local traffic, constructed to a gauge of 1 metre, 8·86 miles in length, and laid on the common road, which inclines upwards from Lausanne to Echellens. The ruling inclines are heavy; they are as follows:—

| | | Yards |
|---|---|---|
| 1 in 28 | for | 545 |
| 1 in 40 | ,, | 578 |
| 1 in 31 | ,, | 236 |
| 1 in 25 | ,, | 655 |
| | | 2,014 |

The minimum radius is 100 metres, or 330 feet; in stations, it is 60 metres, or 200 feet.

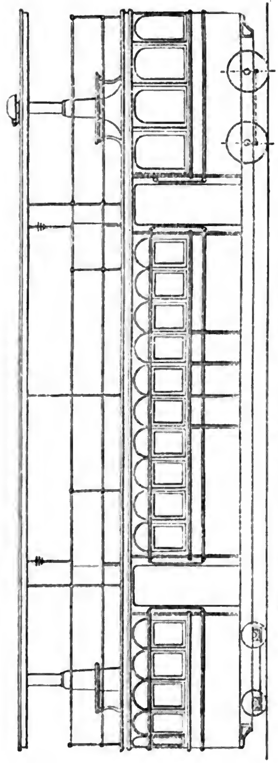


FIG. 123. Double-Bogie Steam-car, by Mr. Brown, 1877. Scale, $\frac{1}{56}$.

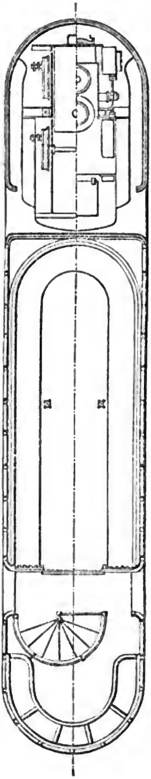


FIG. 124. Mr. Brown's Steam-car. Plan. Scale, $\frac{1}{56}$.

The car, figs. 123, 124, is supported at each end by a four-wheel swivelling bogie. The engine with its boiler complete is supported on one of the bogies, the wheels of which are coupled, and constitute the driving wheels; the locomotive is lodged in one end of the car, where it is wholly masked by the surrounding portion of the car, and is free to revolve on its axis.

The main framing of the car is of joist iron, at such a level that the floor of the car is only 19 inches above the level of the rails. The car is divided into three portions—the saloon furnished with longitudinal seats, upholstered, for 24 passengers; the pavilion at the hind end, over the hind bogie, as a smoking department, for 7 passengers; and the upper story, or imperial, to which a staircase leads from the pavilion, with seats for 30 passengers. Thus, accommodation is provided for 61 passengers in all.

The following are the leading dimensions of the steam-car:—

| | Feet | Inches |
|---|---|---|
| Car :— | | |
| Length over all | 42 | 3½ |
| Extreme breadth | 7 | 9½ |
| Height | 14 | 1 |
| Diameter of bogie-wheels of car | 1 | 5¾ |
| Wheel-base of bogie | 4 | 0 |
| Distance between centres of bogies | 30 | 4¾ |
| Engine :— | | |
| Diameter of steam-cylinders | 0 | 6¼ |
| Length of stroke | 1 | 0 |
| Diameter of coupled wheels | 2 | 3½ |
| Length of wheel-base | 4 | 1 |
| Diameter of boiler | 2 | 3½ |
| Length of flue-tubes | 4 | 7 |

| | Square feet |
|---|---|
| Area of fire-grate | 2·35 |
| Heating surface:—Fire-box | 20 |
| Tubes | 130 |
| Total | 150 |
| Pressure of steam in boiler (per square inch) | 180 lbs. |
| Capacity of water-tanks | 130 gallons |
| Do. coal-bunkers | 5 cwt. |

Weight:—

| | Tons |
|---|---|
| Engine, empty | 5 |
| Do. in working order | 6 |
| Car, empty | 6½ |
| Engine and empty car | 11½ |
| Total weight in working order, with 61 passengers, and luggage | 16 |
| Driving weight, when the car is fully loaded | 10 |
| Net weight of engine and car, in working order, per passenger | 3·77 cwt. |
| Maximum load per driving axle | 5 |
| Do. do. per free axle | 3 |

On Sundays, 600 persons have been carried in eight trips, being 75 passengers at a time. The greatest number taken at a time was 120. It is stated that the ordinary speed was about 9 miles per hour, but speeds of about 19 miles per hour have been attained on a level. The car may be stopped on the steepest gradients within from 16 to 20 feet. It is reported that the engine has never slipped her wheels, even in the most unfavourable weather—in snow, ice, or fog. The fuel, Saarbruck coal, has been consumed at the rate of 11½ lbs. per mile, or ·72 lb. per ton-gross per mile. The daily expenses for working the steam-car at Lausanne, doing 29 miles per day, have been as follows:—

|  | Per day |  |
|---|---|---|
|  | *s.* | *d.* |
| 1 engine driver | 6 | 4 |
| 1 stoker | 2 | 9½ |
| 1 conductor | 3 | 2 |
| Coal (3 cwt.) | 4 | 9 |
| Grease, oil, &c. | 1 | 7 |
|  | 18 | 7 |

or, 7·7*d.* per mile.

It is stated that if the steam-car were worked over a nearly level road, it could easily make 80 miles a day, at a daily expense of 25*s.*, equivalent to 3¾*d.* per mile run. But in this charge there is no element for maintenance. The price of the steam-car is 1,000*l.*[1]

---

[1] The above particulars of the steam-car are taken from *Engineering*, for August 10, 1877, p. 108.

# CHAPTER X.

## DOUBLE-BOGIE STEAM-CAR, BY MR. W. R. ROWAN, COPENHAGEN.

Mr. W. R. Rowan, of Copenhagen, has designed a steam-car for tramways, fig. 125, resembling Mr. Fairlie's steam-carriage, and Mr. Brunner's car, in general arrangement.

Mr. Rowan, however, not recognising the principle of Mr. Fairlie's steam-carriage, reverts to the American railway-carriage, or car, for his prototype, 'the body resting on two bogies or under-carriages'; and 'with a view of affording a suitable place in which the engine may stand,' he naïvely explains that 'the pin of one of the bogies is made hollow and enlarged to several feet in diameter,

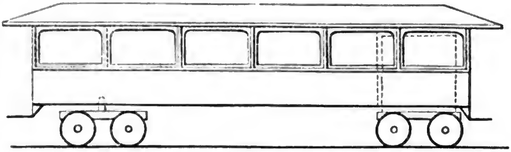


Fig. 125. Double-Bogie Steam-car, by Mr. W. R. Rowan, 1877. Scale, $\frac{1}{114}$.

instead of being a mere pin of metal, and in this hollow pin is fixed the engine, which acts directly upon the bogie-wheels underneath, and thus sets the whole carriage in motion. It is evident that the enlargement of the bogie-pin will not affect the revolving movement of the carriage body upon it; nor will the engine in this position interfere with the arrangements for ascending and descending to or from the upper seats of the car at either end.'[1]

There need not be any doubt of the feasibility of the system. It was amply tested on a working scale by Mr. Fairlie many years ago. The engine may be readily detachable from the body of the car, when required, by the aid of a temporary crutch lowered to support the free end of the car.

Mr. Rowan condenses the exhaust-steam by surface-condensation in a sheet-iron chamber, which is traversed by a number of tubes, either flat or round, from end to end. The steam is exhausted into the chamber, surrounding the tubes; and is condensed by currents of cold air from a fan driven through the tubes on its way to the furnace. By this means, the air may be heated to 190° or 200° F., whilst the steam is effectively condensed, and the condensation-water is pumped again into the boiler. Mr. Rowan considers that from 1,000 to 2,000 square feet of condensing-surface is sufficient for an engine of from 15 to 25 horse-power.

The steam-car last constructed by Mr. Rowan is 32 feet long, over all, built of teak, excepting the side-soles and the roof. It is made to seat 60 passengers inside and outside. The only entrance is at the hinder end. The engine is capable of working to 18 horse-power, with a pressure in the boiler of 150 lbs. per square inch. The cars easily pass on curves of 45 feet radius, and can surmount a gradient of 1 in 20. The total weight of the car and engine is 5 tons. Mr. Rowan gives the following comparative statement of the 'working elements' of a horse-car, a car drawn by a separate engine, and his steam-car:—

---

[1] *The Employment of Mechanical Motors on Tramways.* By W. R. Rowan, C.E.; 1877.

COMPARATIVE 'WORKING ELEMENTS' FOR HORSE-POWER AND STEAM-POWER, ON TRAMWAYS.

| Working elements | Horse car | Car drawn by a separate engine | Steam-car |
|---|---|---|---|
| Number of passengers . | 40 | 40 | 60 |
| Do. servants . . | 2 | 2 | 2 |
| Length of street occupied . | 35 feet | 35 feet | 32 feet |
| Gross weight, including passengers . . . | 5½ tons | 9½ tons | 9½ tons |
| Weight, without passengers . . . . | 2½ ,, | 6½ ,, | 5 ,, |
| Maximum weight on any wheel, with gross load . | 1·375 ,, | 1·375 ,, | 1·50 ,, |
| Maximum weight on any wheel, without load . | ·625 ,, | 1·000 ,, | 1·00 ,, |
| Dead weight per passenger . | 1¼ cwt. | 3 cwt. | 1⅔ cwt. |
| Greatest weight on driving-wheels, with full load . | — | 4 tons | 6 tons |
| Greatest weight on driving-wheels, without load . | — | 4 tons | 4 tons |
| Horse-power for haulage . | 2 h.p. | 18 h.p. | 18 h.p. |
| Steepest working gradient for long runs . . . | 1 in 80 | 1 in 40 | 1 in 20 |

On the results of the trials of his steam-car, Mr. Rowan bases an estimate of the comparative cost of working tramway traffic on his system, and by ordinary horse-traction, assuming that the saving in tear and wear of stock on his system is balanced by the increase in the wear of the road, and leaving, therefore, these causes of expenditure out of the account:—

1*st. Steam-cars.—Daily Expenses.*

| | Kroner | | *s.* | *d.* |
|---|---|---|---|---|
| 1 engineman . . . . . | 7·50 | or | 8 | 3½ |
| $\frac{1}{7}$ reserve do. . . . . . | 1·08 | ,, | 1 | 3 |
| $\frac{1}{4}$ cleaner . . . . . . | 1·12 | ,, | 1 | 3½ |
| Coke . . . . . . . | 9·00 | ,, | 10 | 0 |
| Oil, tallow, waste, &c. . . | 1·50 | ,, | 1 | 8 |
| Sundry petty expenses . . | 2·30 | ,, | 2 | 6 |
| | 22·50 | or | 25 | 0 |

Allowing a day's work of 12 Danish miles, or 56·16 English miles, the expenses are equivalent to 5·34*d.* per English mile, or to ·09*d.* per passenger per mile.

2*nd. Horse-cars.—Daily Expenses.*

The cost for horse-power to the Copenhagen Tramway Company, in 1874, amounted to 2·10 kroner per Danish mile, or 6*d.* per English mile; for a car seated for 40 passengers, equivalent to ·15*d.* per mile.

From these statements, it appears that the expense of working with the steam-car would be absolutely less by ·66*d.*, or 12½ per cent., and that per passenger it would be less by 40 per cent., supposing, of course, that full loads were taken in each case.

# *CONCLUSION.*

In endeavouring to sum up the achievements of tramway practice, and to prognosticate the future of tramways, it must be remembered that their money-earning capacity is something very remarkable. It amounted, in 1876, to 33 per cent. of the capital outlay. The next remarkable thing is, the excessively large working expenditure :—it absorbs three-fourths of the earnings. From the analyses of working expenses which have been made, it is sufficiently clear that the defective point in the service is the supply of tractive power. A horse is a very good motor for turning a gin or drawing a cart; he is out of place on a tramway. What is a tramway? It is, or ought to be, a pair of hard, smooth, regular, and firm bars of iron, or of steel, laid in the street, to be traversed by heavily-laden passenger-cars, much heavier, certainly, than the light elastic omnibus, or the holiday drag. As the omnibus is a fitting load for a pair of horses, the tram-car is, and must be, too great a load for a pair of horses. True, the frictional resistance of tramways is less than that of common street-surfaces. But that is not everything. The resistance of gravity on ascending inclines is just as much for tramways as for pavements, and the labour required for starting a tram-car is much more severe than that required for an omnibus. In a few words, the employment of horses on tramways is a misfit and a barbarism; and when the inertia of prejudice has become exhausted, the civiliser—mechanical power—will duly replace the horse as a motor.

The horse-service is not only a misfit, it is expensive also. It costs, on an average, 55 per cent. of the total expenditure, or 41 per cent. of the receipts, amounting to 13½ per cent. annually on the capital outlay. In absolute money, the average cost is 6½*d.* per mile run by cars. Add to this amount 1*d.* per mile for wages of drivers and pole-shifters, and the total charge for running expenses amounts to 7½*d.* per mile-run.

The question now is, what is to be the cost for mechanical power? There are many minds at work on this problem. It has already been settled by experience that the ordinary running expenses for steam-power on tramways—and no other motor need meantime be taken into the comparison—can be met for 3*d.* per mile-run. The charge for maintenance and renewal of the steam-motor is yet to be settled by experience; but it may be estimated approximately as in proportion to the quantity of fuel consumed per mile-run, relatively to locomotives on railways. It appears that, in the year 1876, the average cost for repair and renewal of locomotives on railways was at the rate of 3¼*d.* per train-mile run; and, taking the maximum quantity of fuel consumed per mile-run by a tram-locomotive, with a car, as 8 lbs. per mile-run, against, say, 32 lbs. per mile-run by railway trains—in the ratio of 1 to 4—it is safe to take, for estimation, the cost for repair and renewal of tramway locomotives at a fourth of 3¼*d.*, or ·81*d.* per mile. Allowing 1*d.* per mile, the total cost for steam motive-power on tramways may be taken at 4*d.* per mile-run, as against 7½*d.*, the cost for horse-power. The difference—3½*d.* per mile—amounts to 22 per cent. of the receipts, and to 7¼ per cent. per year on the capital cost.

It thus appears that the saving by the substitution of steam-power for horse-power on tramways, would afford a dividend of 7¼ per cent. on the actual capital expenditure. The prospect is even better than this, for the tramways to be constructed in the future will be made at a much more moderate outlay than the pioneer tramways, which, like many of the earlier railways, were constructed mainly for the promotion of private interests. The average cost of eleven tramways, traversing 130½ miles of street, was shown to have amounted to nearly £19,000 per mile, double way, works and plant—an unreasonably large sum, half as much as the cost per mile of the railways of the United Kingdom. A tramway can be constructed and stocked for two-thirds of that sum, or say, £13,000 per mile of double line, including the sum of £5,000 for paving. Upon this outlay, the proportion of the gross receipts would rise to about 50 per cent. per annum on the capital. Financiers can complete the calculation, to prove the excellent prospects of tramways as dividend-earning properties.

In the mechanical detail of tramways and cars there is, no doubt, room for improvement. The matter of the way has already been discussed at length. Cars should be constructed on double bogies —or, still better, on radiating axles—with loose wheels, for the easy passing on curves and the minimising of tractional resistance, and they should be placed on a wheel-base of sufficient length to secure steadiness of movement. The short wheel-base now in vogue—5 or 6 feet—is absurdly limited. The pitching movement and the shambling pace of tram-cars, arise very much from the shortness of the base, and they are causes of considerable resistance and extra stress on the way and the cars. Draw-springs should be applied to the cars, and the wheels should be large, although, for bogies, it may not be convenient to employ wheels of much larger diameter than those now in use. The results of the performance of the Paris omnibus car, of Mr. Eade's car, and of Mr. Cleminson's car, point to the material advantages that may be hoped for by starting afresh, from a new point of view, and recasting the design of the tram-car. The results of Mr. H. P. Holt's experimental investigations of the tractional resistance of tramways, when these are completed, will, there is no doubt, prove of great practical value for the improvement of tramway exploitation.

In the scheming of the mechanical motor by steam, engineers have enjoyed the advantages accorded by railway experience; for, in its fundamental aspects, the tramway-locomotive may be said to have come ready-made to their hands. For all that, there has been a great deal to do, and something remains to be done, in applying steam-power as a tramway motor, in the working out of which there is scope for nice design and adaptation. It is scarcely worth anyone's while to boast of employing the railway locomotive in its integrity as a tramway engine: that is easily done. But the production of a noiseless, vapourless, smokeless, and handy machine is a problem of another order, for the solution of which railway experience fails to furnish a precedent. The success which has been attained in the employment of mechanical traction, by steam, on tramways, and the prominent position it occupies to-day, have certainly not been attained *per saltum.* They are the outcome of patient industry, intelligent study, and liberal pecuniary outlay; combined with a determined resistance to the opposition of prejudice and of narrow interests. First in order, and foremost in practical performance, is the Merryweather engine, which has, in considerable numbers, been doing effective service on the tramways of Paris, during the last two years, causeless of annoyance or hindrance to the ordinary traffic of the streets. It is also in regular work in popular thoroughfares elsewhere in France, as well as in Germany, Spain, Portugal, and Holland; and even in New Zealand and other colonies. Advantages thus enjoyed abroad, cannot long be denied to the United Kingdom, by suitable legislation. Tramway practitioners only want fair play, unhampered by churlish regulations and by the repressiveness of unintelligent conservatism.

# APPENDIX.

## *TRAMWAY LEGISLATION.*

By the decisions of the Examiner and of the Standing Orders Committee of the House of Lords on the Liverpool Tramway Bill of 1866, it is rendered necessary for promoters of tramways to deposit plans and sections of their proposed undertakings.

### The Tramways Act, 1870.

Part I. Section 4.

*Sub-Section* 1.—Provisional orders, authorising the construction of tramways in any district, may be obtained by the Local Authority of any district.

*Sub-Section* 2.—Power is given to any other persons, with the consent of the Board of Trade and the Local Authority; not otherwise.

Section 7.—Power is given to the Board of Trade to consider the application, and any objections that may be lodged thereto.

Section 8.—Where it appears to the Board of Trade expedient, they may make a Provisional

Order, and such order shall empower the promoters to make the tramways upon the gauge and in manner therein described, and shall contain such provisions as (subject to the requirements of the Act) the Board of Trade, according to the nature of the application and the facts and circumstances of each case, shall think fit; but such order is not to contain any provision for acquiring lands, except to an extent therein limited, and only then by agreement, or to construct a tramway elsewhere than along or across a road, or upon land taken by agreement.

Section 9.—Tramways shall be constructed as near as may be in the middle of the road, and shall not be so laid that, for a distance of 30 feet or upwards, a less surface than 9 feet 6 inches shall intervene between the outside of the footpaths on either side of the road, and the nearest rail of the tramway, if one-third of the owners or one-third of the occupiers of the houses, shops, or warehouses abutting upon the part of the road where such less space shall intervene, as aforesaid, express their dissent from any tramway being so laid.

Section 10.—The nature of the traffic on the tramway, and the tolls to be taken, are to be specified in the Provisional Order.

Section 12.—The Provisional Order is not to be granted until the promoters deposit in the bank, as there prescribed, a sum of not less than 4 per cent. upon the estimated expense, or security of equal value is deposited.

Section 14.—Such Provisional Order is to have no effect, unless confirmed by Act of Parliament, and to be open to parties to petition against the Act and to appear and oppose the Bill in Committee.

SECTION 16.—The Board of Trade may revoke, amend, extend, or vary such Provisional Order by a further Provisional Order, but the application for every such Provisional Order will be subject to the same conditions as the former Provisional Order, and will require its confirmation by an Act of Parliament.

SECTION 18.—If the promoters do not complete the tramway and open it for public traffic within two years from the date of the order, or within any shorter period prescribed in the order; or if, within one year from either of those times, the works are not substantially commenced, or, if commenced, are suspended without a reason sufficient in the opinion of the Board of Trade, the powers given by the order shall cease, except as to so much of the same as is then completed, unless the time be prolonged by the Board, and as to so much of the same as is then completed, the Board may allow the powers to continue and to be exercised if they think fit; but, failing such permission, then so much of the tramway as is then completed shall be deemed to be discontinued, and dealt with according to the provisions relating thereto.

SECTION 19.—When a tramway has been made by a Local Authority, or possession has been acquired by a Local Authority, they may, with the consent of the Board of Trade, lease to any person the right of use thereof, and of demanding and taking authorised tolls and charges, or the Local Authority may leave such tramways open to be used by the public, and may, in respect of such cases, take the tolls and charges authorised; but no Local Authority can place or run carriages upon such tramways, and demand and take tolls and charges in respect of the use of such carriages. Every such lease shall be for a term not exceeding twenty-one years, and at its expiration such lease may, with the consent of the Board, be renewed for a further term not exceeding in any case twenty-one years; the lease to be void if the lessees discontinue the working of the tramway leased.

Part II. of the Act relates to the construction of tramways.

Section 25.—The mode of formation of tramways is set out. If no gauge is prescribed, the gauge is to be such as to admit of the use on such tramways of carriages constructed for use upon railways of a gauge of 4 feet 8½ inches. They are to be laid on a level with the surface of the road.

Section 26.—Power is given to break up streets.

Section 27.—Provision is made for the completion of the works and the reinstatement of the road.

Section 28.—Provision is made for the repair of the part of the road where the tramway is laid.

Section 29 authorises the road authority and the promoters to contract for paving roads on which tramways are laid.

Section 30 makes provision as to gas and water companies.

Section 31 provides for the protection of sewers, &c.

SECTION 32 preserves the rights of authorities and companies, &c., to open roads.

SECTION 33 provides for the settlement of any difference that may arise between the promoters and the road authority by reference to an engineer to be appointed by the Board of Trade.

PART III. contains general provisions:—first, as to carriages.

SECTION 34.—The promoters are to have the exclusive use of the tramways for carriages with flange-wheels or other wheels suitable only to run on the prescribed rail, and shall be moved by the power prescribed by the Act; and, where no such power is prescribed, by animal power only, &c. No carriage shall extend beyond the outer edge of the wheels of such carriage more than 11 inches on each side.

SECTION 35.—Licenses to use the tramways may, if the Local Authority, or twenty inhabitant ratepayers, satisfy the Board of Trade that the public are deprived of the full benefit of the tramway, be granted to third parties by the Board of Trade on the conditions in the section therein set out. Then follow sections to enforce payment of tolls, and as to licenses.

SECTION 41 relates to the discontinuance of tramways. If the working of a tramway, or of any part thereof, is discontinued for the space of three months (such discontinuance not being occasioned by circumstances beyond the control of the promoters), the powers of the promoters in respect of such disused tramway, or portion thereof, may be determined by an order of the Board of Trade. At any time after two months from the date of such order, the road authority may remove the disused portion of tramways at the cost of the promoters.

SECTION 42 relates to the insolvency of promoters. The Board of Trade may, on finding that the promoters are insolvent, make an order declaring that the powers of the promoters shall cease at the expiration of six months from the date of the order, unless the same are purchased by the Local Authority, who may, in that event, remove the tramway at the cost of the promoters.

SECTIONS 43 and 44 relate to the purchase and sale of tramways.

SECTION 46 enables the Local Authority to make bye-laws as to the rate of speed, the clear distances between any two carriages travelling on the same line of rails, the stopping of carriages using the tramway, and the traffic on the road in which the tramway is laid.

SECTION 48 gives the Local Authority power to license the drivers and conductors.

SECTION 54.—Any person, not duly authorised, using a tramway with carriages having flange-wheels, or other wheels suitable only to run on such tramway, becomes liable to a penalty not exceeding twenty pounds.

SECTION 62 reserves the right of the public to pass along or across any part of a road in which a tramway is laid, whether on or off the tramway, with carriages not having flange-wheels.

### THE TRAMWAYS ORDERS CONFIRMATION ACTS.

That Provisional Orders made by the Board of Trade under the authority of the Tramways Act, 1870, may acquire validity and force, they must be confirmed by special Acts of Parliament. These are distinguished as 'Tramways Orders Confirmation Acts,' by which the Orders set out in the schedules to the Acts respectively are confirmed.

### USE OF MECHANICAL POWER ON TRAMWAYS.

A Select Committee of the House of Commons collected, early in 1877, a mass of evidence on the use of mechanical power on tramways, which was printed with their Report in the same year.[1] No action has yet (February 1878) been taken on their Report, although it was favourable to the use of mechanical power. A movement is now in progress by those interested in tramways with a view to urge upon the Government the importance of legalising the employment of mechanical power on tramways.

---

[1] 'Report from the Select Committee on Tramways (Use of Mechanical Power), with Minutes of Evidence,' April 1877.

# INDEX.

ADELAIDE Tramways, Mr. Kincaid's system for, 83
Anvers, tramways at, 181, 183
Axle-boxes of tram-cars, 275, 286

BALDWIN Locomotive Works, steam-car constructed at, 341; cost of running it, 343
Barcelona, Messrs. Merryweather & Sons' locomotives in, 391
Barker, Mr. Benjamin; his system of iron way at Manchester, 137; cost, 141; his system for light traffic, 142; his groove, 201; his iron substructure, 207
Baxter, steam-car by, 321
Beaumont, Major, his compressed-air car, 385
Bèdé & Co, hot-water steam-car by, 336
Belfast Harbour Tramway:—Lizars' way, 165; Salmond's way, 166
Belfast Tramways:—Construction, 51
Beloe, Mr. Charles, Southport Tramways designed by, 127; Wirral tramway by, 130; new double-rail system by, 133, 210
Birkenhead, Train's tramway at, 16; length, 28
Block-sleeper, Mr. Cockburn-Muir's, 75
Boston, cast-iron tram-rails in, 10
Brakes of tram-cars, 276, 289
Brevoort, Mr. H. L., test of locomotive by, 319
Bristol Tramway:—Construction, 83, 117; cost, 120
Brompton, West, trial of the Grantham steam-car at, 323
Brown, Mr. A., steam-car by, 406
Brussels, Mr. Loftus Perkins' condensing locomotive in, 328
Brussels, tramways in, 179; sections of rails, 180; cost, 183
Buel, Mr. R. H., test of locomotive by, 319
Buenos Ayres, tramway system of, 14; Livesey's system, 71; Cockburn-Muir's system, 78

CARS, steam. *See* STEAM-CARS
Cars, tramway, 274; original car, 274; weight of cars, by Mr. Martineau, 278; 'dead-weight,' 280; inside-and-outside car, by the Metropolitan Railway Carriage and Waggon Company, 282; inside car, by the Starbuck Car and Waggon Company, 293; radial-axle car, by Mr. James Cleminson, 295; bearing-springs, 300; car-wheels, 304; French tram-cars, 306; Eade's reversible car, 310

Cassel Tramway, 188

Cincinatti Tramway, steam-car on, 312

Cleminson, Mr. James, radial-axle passenger-car by, 295

Cockburn-Muir's iron way, or 'block-sleeper' system, 75; at Monte Video, &c., 76; tests of his rails for transverse strength by Mr. Kirkaldy, 78; in advance of its time, 193; his span of bearings, 203; his substructure, 208

Cockerell's hot-water locomotive, 368

Colebrooke Dale Iron Company, cast-iron tram-rails laid by, 4

Compagnie Générale des Omnibus, tram-omnibus by, 307

Compressed-air locomotives, 375; data, 375; compressed-air car, by M. Mékarski, 382; compressed-air car, by Mr. Scott-Moncrieff, 384; compressed-air car, by Major Beaumont, 385

Coney Island Railroad, trial of Ransom car on, 347

Constantinople, tramways in:—Construction, 184; cost, 185

Cost, capital, of tramways, analysis of, 265

Cost, first, of tramways:—Table of cost of tramways opened at June 30, 1876, 28; Glasgow Corporation, 44, 114; Dublin, 58; London Tramways, 68; Livesey's grooved-rail tramway, 74; Cockburn-Muir's iron way, 78; Dewsbury, Batley, and Birstal (Kincaid), 83; Dowson's iron way, 87; Schenck's iron way, 89; Edinburgh Street, 97; Dundee, 105; Bristol (Kincaid), 120; Leicester (Kincaid), 121; Salford Corporation (Kincaid), 126; Southport Street (Beloe), 128; Wirral (Beloe), 131; Manchester (Barker), 141, 142; Liverpool (Deacon), 152; Robinson Souttar's way, 160; Glasgow Harbour (Ransome, Deas, & Rapier), 163; the same system for lighter traffic, 164; Belfast Harbour (Salmond), 168; tramways in Paris, 173, 174; tramways in Brussels, 183; Constantinople, 185

Copenhagen, trial of Kohl's locomotive in, 331; Smith & Mygind's locomotive, 331; Mr. W. R. Rowan's steam-car, 411

Cost, general, and working expenditure of tramways, 211; North Metropolitan, 213; London, 220; London Street, 228; Dublin, 232; Glasgow Corporation, 238; Vale of Clyde, 242; Edinburgh, 243; Leeds, 247; Sheffield, 249; Southport, 250; Provincial—Plymouth, Cardiff, Portsmouth, 251; Dewsbury, Batley, and Birstal, 253

Crossings and points, for the Liverpool Tramways, 151

Curry, Mr. Matthew, on the Lisbon Steam Tramway, 190

DEACON, Mr. George F.; his systems of tramway, laid at Liverpool, 143; bearing-surface of his rail, 195; merits of the system, 209

Deas, Mr. James; his report on the cast-iron tramway at Glasgow Harbour, 163

Dewsbury, Batley, and Birstal Tramway:—Construction, 82; general cost and working expenditure, 253

Dowson's iron way, 84; cost, 87

Dublin Tramways:—Construction, 54; cost, 58; general cost and working expenditure, 232

Dundee Street Tramways, system of, 101; gradients, 102; construction, 103; cost, 105

EADE'S reversible car, 310
Edinburgh Street Tramways, system of, 91; gradients and curves, 92; construction, 93; cost, 97; general cost and working expenditure, 243
Expenditure, working of tramways, general analysis of, 271. *See* also Cost (General), &c.
Expenses, working. *See* Working Expenses, Cost (General), &c.

FAIRLIE, Mr. R. F., reference to his double-bogie steam-carriage, 406, 411, 412
Fowler, Mr. A. M., design of Salford Corporation Tramways by, 121; his groove, 201
Francq, M. Léon, design of Versailles Tramways by, 176; tram-cars by, 306; hot-water locomotive by, 332

GAND, tramways in, 182, 183
Geneva Tramways, construction of, 179
Glasgow Corporation Tramways, Act for, 37; first system of construction, 37; gauge of the way, 39; cost of construction of the first contract, 44; second system of construction, 108, 202; gradients, cost, 114; general cost and working expenditure, 238
Glasgow Harbour, tramway at, 79; construction, 161; cost, 163
Goschler, M., prices for tramways in Paris, by, 173; cost of Constantinople tramways, 185
Grantham, Mr. John, steam-cars by, 322, 325
Greenwood, Mr., on compressed-air locomotives, 386
Grice & Long, Messrs., steam-car by, 312
Gauge of way:—Early timber tramways, 3; in Philadelphia, 11; in the United States, 14; at Birkenhead, 16; in Liverpool, 21; railway gauge required by Act of Parliament, 21; in Glasgow, 39; in Belfast, 51; in Dublin, 56; on the Vale of Clyde, 59; in Buenos Ayres, 71; in Monte Video, 78; in Bahia, 78; at Madras, 84; in Edinburgh, 92; in Dundee, 102; in Bristol, 117; in Salford, 123; in Southport, 127; in Wirral, 130; in Manchester, 139; Paris, 169, 172; Brussels, 179; Anvers, 180; Liège, 180; Gand, 180; Moscow, 186; Leipzig, 187; Lisbon, 189; Wellington, 190

HALL, Sir Benjamin, on Train's tramway, 15
Handyside car-wheel, 304
Harbour tramways:—Ransome, Deas, and Rapier's cast-iron way at Glasgow Harbour, 79, 161; cost, 163; system for lighter traffic, 164. Belfast Harbour Tramway:—Lizars' way, 165; Salmond's way, 166
Haworth's tramway at Salford, 18
Holt, Mr. Henry P., on frictional resistance of tram-cars, 349; auxiliary compound incline-locomotive, 395
Hope, Mr. Beresford, evidence on tramways by, 9, 17
Hopkins, Mr. George, on margin of pavement for tramways, 25; engineer of tramways in London, 30; and of the Dublin Tramways, 54; and of the Vale of Clyde Tramways, 59; reconstruction of the North Metropolitan Tramways, 66
Horses, cost for maintenance and renewal. *See* Cost (General); Working Expenses; London General Omnibus Company

Hot-water locomotives and steam-cars:—Historical sketch, 312; Mr. Buel's report, 319; M. Léon Francq's hot-water locomotive, 332; Mr. L. J. Todd's hot-water steam-car, 335; MM. Bède & Co.'s hot-water steam-car, 336. Data for hot-water power, 366, 374; Cockerell's hot-water locomotive, 368
Hoylake and Birkenhead Tramway, trial of Grantham car on, 327
Hughes, Mr. Henry, steam-locomotive by, 338; trial on the Leicester Tramways, 340; and on the Edinburgh, the Sheffield, and the Vale of Clyde Tramways, 341; on frictional resistance of tram-cars, 349
Huntingdon, on cost of London Tramways, 68

IRON substructures for tramways:—Livesey's, 71; Cockburn-Muir's, 75; Kincaid's, 79, 117, 120, 121; Dowson's, 84; Schenk's, 87; Beloe's, 133; Barker's, 136; Ransome, Deas & Rapier's, 161, 164; at Lille, 178

KINCAID, Mr. Joseph:—Construction of the Greenwich line, 33; of the Leeds Tramway, 35, 81; his iron way, as patented, 79; iron way at Sheffield, 81; his second patent, 83; his way on the Bristol Tramways, 117; on the Leicester Tramways, 120; on the Salford Corporation Tramways, 121; his system of keeping to gauge, 197; his substructure, 203, 206, 208 his span of bearings, 203
Kirkaldy, Mr. David, tests of tram-rails by, 78; test of indiarubber springs by, 303
Kohl, Mr. A., tram-locomotive by, 331

LAMM, Dr. Emile, ammoniacal-gas car by, 316; hot-water locomotive by, 317
Larsen, rail and fastening by, 48; applied to the London Street Tramways, 50; to the Belfast Tramways, 51; advantages of the fastening, 49, 193
Latta, Mr. A. B., steam-car by, 312
Lausanne and Echellons Branch Railway, Mr. Brown's steam-car on, 406
Lebout, M., Constantinople Tramways designed by, 184
Leeds Tramway, construction of, 35; general cost and working expenditure, 247
Legislation for tramways, 420
Leicester Tramways:—Construction and cost, 120; employment of steel rails, 206; trials of Mr. Hughes' locomotive on, 340
Leipzig Tramways, 187
Liège, tramways at, 180, 183
Light, Mr. C. L., cast-iron tram-rail by, 10, 201; cast-iron car-wheel by, 305
Lille, tramways at; construction, 178
Lisbon Tramways, 189; performance of locomotives, 189
Liverpool, Noble's crescent-rail in, 19; Acts for tramways in, 20; system of tramways, 20, 28; construction of them, 21; gradients, 25; reconstructed on Mr. G. F. Deacon's system of tramway, 143; cost, 152; crossings and points, 151
Livesey's iron way, 14; at Buenos Ayres, with steel rails, 72; with iron rails, 74; in advance of its time, 193; his coupled stools, 203; span of bearings, 203
Lizars, his system of tramway at Belfast Harbour, 165
Locomotives, steam. *See* STEAM-LOCOMOTIVES.

London General Omnibus Company:—Capital cost and working expenditure, 258

London Street Tramways, Acts obtained for, 26; length, 28; construction, 50; inclines and curves, 70; general cost and working expenditure, 228

London Tramways, Acts obtained for, 26; length, 28; construction 30, 33; cost of, 68; inclines of, 70; general cost and working expenditure, 220

Loûbat, tramways by, in New York, 6; in Paris, 169

Lynde, Mr. J. H., construction of Manchester Corporation Tramways under, 137; on the width of base in Barker's system, 207

MADRAS Tramways, construction of, 84

Manchester and Sheffield Railway, trial of the Perkins' tram-locomotive on, 329

Manchester Corporation Tramways, system of, 136; construction, 137; cost, 141

Martineau, Mr.; his table of weights of cars, 278

Mechanical power on tramways, 312; historical sketch, 312; elementary data, 349; hot-water locomotives, 366; compressed-air engines, 375; locomotives by Messrs. Merryweather & Sons, 387; auxiliary compound incline-locomotive, by Mr. Henry P. Holt, 395; condensing-locomotive, by Mr. Loftus Perkins, 399; Bissell-bogie steam-car, by Mr. Edward Perrett, 403; double-bogie steam-car, by Mr. A. Brown, 406; double-bogie steam-car, by Mr. W. R. Rowan, 411

Mechanical power, Elementary data:—resistance to traction on a railway, 349, 352; Mr. H. P. Holt's experiments on grooved rails, 349; Mr. Hughes' experiments, 349; causes of resistance, 350; M. Tresca's experiments, 350; M. Deloncbant's experiments, 351; Colonel Sytenko's experiments, 351; Mr. Wood's estimate, 352; Messrs. Merryweather's conclusions, 353; Mr. John Phillips' experiments in starting cars, 353

Mechanical propulsion, with rules, 353; adhesion, 356; influence of gradients, 356; steam consumed, 358; properties of steam, 360; examples of the use of the rules, 362; data for water and fuel, 365

Hot-water power, 366; Cockereil's hot-water engine, with results of experiments, 368

Compressed-air power, 375

Mékarski's compressed-air car, 382

Merryweather & Sons, steam-locomotive by, 337; locomotives on the Paris Tramways, 338, 387; auto-absorbing apparatus, 338; calculation of the performance of their locomotives, 362, 389, 392

Metropolis, tramways in, 26; length, 26, 28; inclines and curves on, 69

Metropolitan Railway Carriage and Waggon Company, inside-and-outside passenger-car by, 282

Morris, Mr. J., on margin of pavement for tramways, 25

Moscow Tramways, 186

NEW YORK, East, and Canartio tramway, hot-water locomotives on, 319; tests by Mr. Buel and Mr. Brevoort, 320

New York:—Grooved tram-rails, 6, 200; step-rails, 13

Noble's crescent-rail, 19

North British Rubber Company, indiarubber springs by, 288, 301

North Metropolitan Tramways, Acts obtained for, 26; length, 28; construction of, 30; reconstruction of, 66; inclines and curves, 69; general cost and working expenditure, 213

OMNIBUS Company, London General:—Capital cost and working expenditure, 258

Orleans, New, ammoniacal-gas car on, 316; hot-water locomotive on, 317

PARIS, Messrs. Merryweather & Sons' locomotives in, 338, 388

Paris, tramways in, 169; cost, 173, 175

Perkins, Mr. Loftus, condensing-locomotive by, 328, 399

Perrett, Mr. Edward, steam-car by, 403

Philadelphia, step-rails in, 11; trial of steam-cars, 342, 347; cost of running steam-cars, 344

Phillips, Mr. John, on the resistance of starting a car, 353

Provincial tramways:—General cost and working expenditure, 251

RADIAL-AXLE car, by Mr. James Cleminson, 295

Rails:—Early timber, 2; early cast-iron, 4; grooved-iron rails in New York, 6; Light's cast-iron rail in Boston, U.S., 10; Philadelphia step-rail, 11; New York step-rail, 13; Train's step-rail, 16; Haworth's flat-rail, 18; Noble's crescent-rail, 19; early Liverpool rail, 22, 24; objections to the flat-rail, 32; rail for the London Tramways, 34 early Leeds rail, 36; Johnstones and Rankine's rails, 38, 42, 110; Larsen's rail, 48, 50, 51; Dublin, 55; Vale of Clyde, 60; North Metropolitan, 67; Livesey's steel rail, 71, 72; Livesey's iron rail, 74; Cockburn-Muir's iron rail, 75; Kincaid's iron rail, 80, 82, 83, 118, 124; Dowson's iron rail, 84, 85; Schenk's iron rail, 87; Macrae's iron rail, 94; Mackison's iron rails, 104; Kincaid's steel rail, 120; Beloe's rails, 130, 132, 133; Barker's steel rail, 138, 142; Deacon's steel rail, 144, 152; Souttar's steel rail, 157, 158; Ransome, Deas & Rapior's cast-iron rail, 161, 164; Lizars iron rail, 165; Salmond's iron rail, 166, 167; Loûbat's rail, 169; iron rails in Paris tramways, 170, 171, 174; Francq's iron rail, 176; Lille iron rail, 178; iron rails in Brussels, 179; at Anvers, 181; at Liège, 182; at Gand, 182; Lebout's iron rail, 184; Sytenko's rail, 186; Leipzig rail, 187; Cassel iron rail, 188; Lisbon iron rail, 189; Wellington iron rail, 190

Consideration of the design and strength of rails, 192, 204

Ransom, Mr. Louis, steam-car by, 345; trials of steam-car, 347

Ransome, Deas, & Rapior's cast-iron way at Glasgow Harbour, 79, 161, 164; cost, 163, 164; width of bearing, 207

Receipts of tramways, summary, 269. *See* also COST (GENERAL), &c.

Resistance on tramways:—Freedom of Mr. C. L. Light's sloping-berme, 10; freedom of the step-rail, 13; freedom of Mr. Haworth's flat-rail, 18; disadvantage of the crescent-rail, 20; advantage of the round contour of the groove, 35; advantage of

the shallow groove, 41, 61; central-bearing for wheels, 118; advantage of a first-rate rolling-surface, 192; causes of resistance, 201, 277, 350; necessity for vertical stiffness, 204; reduction of resistance by the use of radial axles and loose wheels, 295; by the use of elastic-wheels, 304
Resistance of cars to traction, 307, 308; advantage of lightness and elasticity, 311. *See* also MECHANICAL POWER (ELEMENTARY DATA).
Rolling surface, good, advantage of, 192
Rowan, Mr. W. R., steam-car by, 411

SALFORD, Haworth's tramway in, 18; Corporation tramways, construction of, 121; Eade's reversible car on the Manchester Corporation tramways, 310
Salmond, Mr. T. R.; his system of tramway at Belfast Harbour, 166
Santander, Tram Via de, steam-locomotive for, 314
Schenk's iron way, 87; cost, 89
Scott-Moncrieff's compressed-air car, 384
Sheffield Tramways:—Construction, 81; latest practice, 198, 206; general cost and working expenditure, 249
Smith & Mygind's locomotive, 331
Société Métallurgique et Charbonnière, three-cylinder locomotive by, 330
Southport Tramways:—Construction, 127; cost, 128; general cost and working expenditure, 250
Souttar, Mr. Robinson; his system of tramway, 155; its cost, 160; on the cost of tramways, 192; his bevelled sleepers, 199; his rail, 202
Spencer, George, & Co., indiarubber springs by, 300
Springs, bearing, of tram-cars, 275, 289, 300
Starbuck Car and Waggon Company, inside-passenger car by, 293
Steam-cars:—Historical sketch, 312; Grantham steam-car, 322; Mr. L. J. Todd's steam-car, 335; MM. Bède & Co.'s steam-car, 336; Baldwin steam-cars, 341; Mr. Ransom's steam-car, 345; Mr. Edward Perrett's steam-car, 403; Mr. A. Brown's steam-car, 406; Mr. W. R. Rowan's steam-car, 411
Steam-locomotives:—On Lisbon Tramways, 189; historical sketch, 312; locomotives by Messrs. Merryweather & Sons, 337, 387; locomotive by Mr. Henry Hughes, 338; auxiliary compound incline-locomotive by Mr. Henry P. Holt, 395; condensing-locomotive by Mr. Loftus Perkins, 328, 399
Stephenson, Mr. John, original tram-car by, 274
Step-rails, in Philadelphia, 11; in New York, 13; at Birkenhead, &c., 16
Sterne, L., & Co., rubber-centre spiral springs by, 302
Strength, transverse, of Mr. Cockburn-Muir's iron rail, 79
Substructures, iron, for tramways. *See* IRON SUBSTRUCTURES.
Sytenko, Colonel, Moscow Tramways designed by, 186

TODD, Mr. Leonard J., steam-locomotive by, 313; hot-water steam-car by, 334
Train, Mr. G. F., tramway, 15; his tramway at Birkenhead, 16; in London, 17; in the Potteries, 17; steam-car, 312
Tram-rails. *See* RAILS.
Tramway legislation, 420

Tramways:—Definition, 1; historical notice, 2; early timber tramways, 2; cast-iron tram-rails, 4, 10; tramways in the United States, 6; the first Liverpool tramway, 19; tramways in London, 26, 30, 48, 66, 213, 220, 228; Acts for tramways, 27; table of tramways at June 30, 1876, 28; the Leeds Tramways, 35, 81, 117, 247; Glasgow, 37, 79, 108, 161, 238; Vale of Clyde, 41, 59, 242; Belfast, 51, 165; Dublin, 54, 232; Buenos Ayres, 71, 78; Monte Video, 76; Salto, 78; Bahia, 78; Vienna, 78; Palermo, 78; Sheffield, 81, 117, 249; Dewsbury, 82, 253; Adelaide, 83; Madras, 84; Edinburgh, 91, 243; Dundee, 101; Bristol, 117; Hull, 117; Leicester, 120; Salford, 18, 121; Southport, 127, 250; Wirral, 130; Manchester, 136; Liverpool, 143; Provincial, 251; Plymouth, 251; Cardiff, 251; Portsmouth, 251; Paris, 169; Versailles, 176; Lille, 178; Belgium, 179; Brussels, 179, 183; Anvers, 181, 183; Liège, 181, 183; Gand, 182, 183; Constantinople, 184; Moscow, 186; Leipzig, 187; Cassel, 186; Lisbon, 189; Wellington, 190
 General conclusions on the design and construction of tramways, 191; cost, 211, 265; receipts, 269; working expenditure, 271; conclusion, 415; legislation, 420

VALE of Clyde Tramways, Act for, 59; construction, 60; widening of the gauge, 208; general cost and working expenditure, 242
Vaucamps, M., on the performance of the Perkins locomotive, 329
Versailles Tramways, construction of, 176
Vienna Tramways, trial of Grantham car on, 327

WANTAGE Railway, the Grantham car on; cost of working it, 324
Washington step-rail, 14
Way, gauge of. *See* GAUGE OF WAY.
Wellington City Tramways, 190
Wheels and axles of tram-cars, 276, 284, 291, 294, 304
Wirral Tramway:—Construction, 130; cost, 131
Woods, Mr. Edward, improvements of the Grantham car by, 324; on resistance of tram-cars, 352
Working expenses on tramways:—Analysis of cost for horse-power on the *Tramway Sud*, 175; cost for horses and cars in Brussels, 183; cost of working the Grantham car on the Wantage Tramway, 325; cost of running the Baldwin steam-car, 343; cost of running horse-cars in Philadelphia, 344; cost of working Mr. Brown's steam-car at Lausanne, 410; cost of working steam-cars and horse-cars in Copenhagen, 414; cost of working steam-locomotives, 423. *See also* COST (GENERAL).

LONDON: PRINTED BY
SPOTTISWOODE AND CO., NEW-STREET SQUARE
AND PARLIAMENT STREET

LONDON, *March*, 1878.

# A Catalogue of Books

INCLUDING MANY

# NEW & STANDARD WORKS

IN

ENGINEERING, ARCHITECTURE,
AGRICULTURE, MATHEMATICS, MECHANICS,
SCIENCE, &c. &c.

PUBLISHED BY

**CROSBY LOCKWOOD & CO.,**
7, STATIONERS'-HALL COURT, LUDGATE HILL, E.C.

## ENGINEERING, SURVEYING, &c.

### *Humber's New Work on Water-Supply.*

A COMPREHENSIVE TREATISE on the WATER-SUPPLY of CITIES and TOWNS. By WILLIAM HUMBER, Assoc. Inst. C.E., and M. Inst. M.E. Author of "Cast and Wrought Iron Bridge Construction," &c. &c. Imp. 4to. Illustrated with 50 Double Plates, 2 Single Plates, Coloured Frontispiece, and upwards of 250 Woodcuts, and containing 400 pages of Text, elegantly and substantially half-bound in morocco. 6*l*. 6*s*.

*List of Contents:—*

I. Historical Sketch of some of the means that have been adopted for the Supply of Water to Cities and Towns.—II. Water and the Foreign Matter usually associated with it.—III. Rainfall and Evaporation.—IV. Springs and the water-bearing formations of various districts.—V. Measurement and Estimation of the Flow of Water.—VI. On the Selection of the Source of Supply.—VII. Wells.—VIII. Reservoirs.—IX. The Purification of Water.—X. Pumps.—XI. Pumping Machinery.—XII. Conduits.—XIII. Distribution of Water.—XIV. Meters, Service Pipes, and House Fittings.—XV. The Law and Economy of Water Works.—XVI. Constant and Intermittent Supply.—XVII. Description of Plates.—Appendices, giving Tables of Rates of Supply, Velocities, &c. &c., together with Specifications of several Works illustrated, among which will be found:—Aberdeen, Bideford, Canterbury, Dundee, Halifax, Lambeth, Rotherham, Dublin, and others.

OPINIONS OF THE PRESS.

"The most systematic and valuable work upon water supply hitherto produced in English, or in any other language."—*Engineer* (first notice).

"Mr. Humber's work is characterised almost throughout by an exhaustiveness much more distinctive of French and German than of English technical treatises."—*Engineer* (third notice).

"We can congratulate Mr. Humber on having been able to give so large an amount of information on a subject so important as the water supply of cities and towns. The plates, fifty in number, are mostly drawings of executed works, and alone would have commanded the attention of every engineer whose practice may lie in this branch of the profession."—*Builder*.

## *Humber's Modern Engineering. First Series.*

A RECORD of the PROGRESS of MODERN ENGINEERING, 1863. Comprising Civil, Mechanical, Marine, Hydraulic, Railway, Bridge, and other Engineering Works, &c. By WILLIAM HUMBER, Assoc. Inst. C.E., &c. Imp. 4to, with 36 Double Plates, drawn to a large scale, and Photographic Portrait of John Hawkshaw, C.E., F.R.S., &c. 3*l.* 3*s.* half morocco.

*List of the Plates.*

| NAME AND DESCRIPTION. | PLATES. | NAME OF ENGINEER. |
|---|---|---|
| Victoria Station and Roof—L. B. & S. C. Rail. | 1 to 8 | Mr. R. Jacomb Hood, C.E. |
| Southport Pier ............................ | 9 and 10 | Mr. James Brunlees, C.E. |
| Victoria Station and Roof—L. C. & D. & G. W. Railways ............................ | 11 to 15A | Mr. John Fowler, C.E. |
| Roof of Cremorne Music Hall .............. | 16 | Mr. William Humber, C.E. |
| Bridge over G. N. Railway ................ | 17 | Mr. Joseph Cubitt, C.E. |
| Roof of Station—Dutch Rhenish Railway .. | 18 and 19 | Mr. Euschedi, C.E. |
| Bridge over the Thames—West London Extension Railway ........................ | 20 to 24 | Mr. William Baker, C.E. |
| Armour Plates ............................ | 25 | Mr. James Chalmers, C.E. |
| Suspension Bridge, Thames ................ | 26 to 29 | Mr. Peter W. Barlow, C.E. |
| The Allen Engine ........................ | 30 | Mr. G. T. Porter, M.E. |
| Suspension Bridge, Avon .................. | 31 to 33 | Mr. John Hawkshaw, C.E. and W. H. Barlow, C.E. |
| Underground Railway .................... | 34 to 36 | Mr. John Fowler, C.E. |

With copious Descriptive Letterpress, Specifications, &c.

"Handsomely lithographed and printed. It will find favour with many who desire to preserve in a permanent form copies of the plans and specifications prepared for the guidance of the contractors for many important engineering works."—*Engineer.*

## *Humber's Modern Engineering. Second Series.*

A RECORD of the PROGRESS of MODERN ENGINEERING, 1864; with Photographic Portrait of Robert Stephenson, C.E., M.P., F.R.S., &c. 3*l.* 3*s.* half morocco.

*List of the Plates.*

| NAME AND DESCRIPTION. | PLATES. | NAME OF ENGINEER. |
|---|---|---|
| Birkenhead Docks, Low Water Basin ...... | 1 to 15 | Mr. G. F. Lyster, C.E. |
| Charing Cross Station Roof—C. C. Railway. | 16 to 18 | Mr. Hawkshaw, C.E. |
| Digswell Viaduct—Great Northern Railway. | 19 | Mr. J. Cubitt, C.E. |
| Robbery Wood Viaduct—Great N. Railway. | 20 | Mr. J. Cubitt, C.E. |
| Iron Permanent Way ...................... | 20A | — |
| Clydach Viaduct—Merthyr, Tredegar, and Abergavenny Railway .................. | 21 | Mr. Gardner, C.E. |
| Ebbw Viaduct ditto ditto ditto | 22 | Mr. Gardner, C.E. |
| College Wood Viaduct—Cornwall Railway .. | 23 | Mr. Brunel. |
| Dublin Winter Palace Roof ................ | 24 to 26 | Messrs. Ordish & Le Feuvre. |
| Bridge over the Thames—L. C. & D. Railw. | 27 to 32 | Mr. J. Cubitt, C.E. |
| Albert Harbour, Greenock ................ | 33 to 36 | Messrs. Bell & Miller. |

With copious Descriptive Letterpress, Specifications, &c.

"A *résumé* of all the more interesting and important works lately completed in Great Britain; and containing, as it does, carefully executed drawings, with full working details, it will be found a valuable accessory to the profession at large."—*Engineer.*

"Mr. Humber has done the profession good and true service, by the fine collection of examples he has here brought before the profession and the public."—*Practical Mechanics' Journal.*

## *Humber's Modern Engineering. Third Series.*

A RECORD of the PROGRESS of MODERN ENGINEERING, 1865. Imp. 4to, with 40 Double Plates, drawn to a large scale, and Photo Portrait of J. R. M'Clean, Esq., late President of the Institution of Civil Engineers. 3*l.* 3*s.* half morocco.

*List of Plates and Diagrams.*

MAIN DRAINAGE, METROPOLIS,

NORTH SIDE.

Plate 1. Map showing Interception of Sewers.—2 and 3. Middle Level Sewer. Sewer under Regent's Canal; and Junction with Fleet Ditch.—4, 5, and 6. Outfall Sewer. Bridge over River Lea. Elevation and Details.—7. Outfall Sewer. Bridge over Marsh Lane, North Woolwich Railway, and Bow and Barking Railway Junction.—8, 9, and 10. Outfall Sewer. Bridge over Bow and Barking Railway. Elevation and Details.—11 and 12. Outfall Sewer. Bridge over East London Waterworks' Feeder. Elevation and Details.—13 and 14. Outfall Sewer. Reservoir. Plan and Section.—15. Outfall Sewer. Tumbling Bay and Outlet.—16. Outfall Sewer. Penstocks.

SOUTH SIDE.

Plates 17 and 18. Outfall Sewer. Bermondsey Branch.—19, 20, 21, and 22.

MAIN DRAINAGE, METROPOLIS,

*continued—*

Outfall Sewer. Reservoir and Outlet. Plan and Details.—23. Outfall Sewer. Filth Hoist.—24. Sections of Sewers (North and South Sides).

THAMES EMBANKMENT.

Plate 25. Section of River Wall.—26 and 27. Steam-boat Pier, Westminster. Elevation and Details.—28. Landing Stairs between Charing Cross and Waterloo Bridges.—29 and 30. York Gate. Front Elevation. Side Elevation and Details.—31, 32, and 33. Overflow and Outlet at Savoy Street Sewer. Details; and Penstock.—34, 35, and 36. Steam-boat Pier, Waterloo Bridge. Elevation and Details.—37. Junction of Sewers. Plans and Sections.—38. Gullies. Plans and Sections.—39. Rolling Stock.—40. Granite and Iron Forts.

With copious Descriptive Letterpress, &c.

---

## *Humber's Modern Engineering. Fourth Series.*

A RECORD of the PROGRESS of MODERN ENGINEERING, 1866. Imp. 4to, with 36 Double Plates, drawn to a large scale, and Photographic Portrait of John Fowler, Esq., President of the Institution of Civil Engineers. 3*l.* 3*s.* half morocco.

*List of the Plates and Diagrams.*

| NAME AND DESCRIPTION. | PLATES. | NAME OF ENGINEER. |
|---|---|---|
| Abbey Mills Pumping Station, Main Drainage, Metropolis | 1 to 4 | Mr. Bazalgette, C.E. |
| Barrow Docks | 5 to 9 | Messrs. M'Clean & Stillman, C.E. |
| Manquis Viaduct, Santiago and Valparaiso Railway | 10, 11 | Mr. W. Loyd, C.E. |
| Adams' Locomotive, St. Helen's Canal Railw. | 12, 13 | Mr. H. Cross, C.E. |
| Cannon Street Station Roof | 14 to 16 | Mr. J. Hawkshaw, C.E. |
| Road Bridge over the River Moka | 17, 18 | Mr. H. Wakefield, C.E. |
| Telegraphic Apparatus for Mesopotamia | 19 | Mr. Siemens, C.E. |
| Viaduct over the River Wye, Midland Railw. | 20 to 22 | Mr. W. H. Barlow, C.E. |
| St. Germans Viaduct, Cornwall Railway | 23, 24 | Mr. Brunel, C.E. |
| Wrought-Iron Cylinder for Diving Bell | 25 | Mr. J. Coode, C.E. |
| Millwall Docks | 26 to 31 | Messrs. J. Fowler, C.E., an William Wilson, C.E. |
| Milroy's Patent Excavator | 32 | Mr. Milroy, C.E. |
| Metropolitan District Railway | 33 to 38 | Mr. J. Fowler, and Mr. T. M. Johnson, C.E. |
| Harbours, Ports, and Breakwaters | A to C | |

*With Copious Descriptive Letterpress, Specifications, &c.*

## *Humber's Great Work on Bridge Construction.*

A COMPLETE and PRACTICAL TREATISE on CAST and WROUGHT-IRON BRIDGE CONSTRUCTION, including Iron Foundations. In Three Parts—Theoretical, Practical, and Descriptive. By WILLIAM HUMBER, Assoc. Inst. C. E., and M. Inst. M.E. Third Edition, revised and much improved, with 115 Double Plates (20 of which now first appear in this edition), and numerous additions to the Text. In 2 vols. imp. 4to, *6l. 16s. 6d.* half-bound in morocco.

"A very valuable contribution to the standard literature of civil engineering. In addition to elevations, plans, and sections, large scale details are given, which very much enhance the instructive worth of these illustrations. No engineer would willingly be without so valuable a fund of information."—***Civil Engineer and Architect's Journal.***

"Mr. Humber's stately volumes lately issued—in which the most important bridges erected during the last five years, under the direction of our most eminent engineers, are drawn and specified in great detail."—***Engineer.***

"A book—and particularly a large and costly treatise like Mr. Humber's—which has reached its third edition may certainly be said to have established its own reputation."—***Engineering.***

## *Strains, Formulæ & Diagrams for Calculation of.*

A HANDY BOOK for the CALCULATION of STRAINS in GIRDERS and SIMILAR STRUCTURES, and their STRENGTH; consisting of Formulæ and Corresponding Diagrams, with numerous Details for Practical Application, &c. By WILLIAM HUMBER, Assoc. Inst. C.E., &c. Second Edition. Fcap. 8vo, with nearly 100 Woodcuts and 3 Plates, *7s. 6d.* cloth.

"The arrangement of the matter in this little volume is as convenient as it well could be. . . . . The system of employing diagrams as a substitute for complex computations is one justly coming into great favour, and in that respect Mr. Humber's volume is fully up to the times."—***Engineering.***

"The formulæ are neatly expressed, and the diagrams good."—***Athenæum.***

"Mr. Humber has rendered a great service to the architect and engineer by producing a work especially treating on the methods of delineating the strains on iron beams, roofs, and bridges by means of diagrams."—***Builder.***

## *Barlow on the Strength of Materials, enlarged.*

A TREATISE ON THE STRENGTH OF MATERIALS, with Rules for application in Architecture, the Construction of Suspension Bridges, Railways, &c.; and an Appendix on the Power of Locomotive Engines, and the effect of Inclined Planes and Gradients. By PETER BARLOW, F.R.S. A New Edition, revised by his Sons, P. W. BARLOW, F.R.S., and W. H. BARLOW, F.R.S., to which are added Experiments by HODGKINSON, FAIRBAIRN, and KIRKALDY; an Essay (with Illustrations) on the effect produced by passing Weights over Elastic Bars, by the Rev. ROBERT WILLIS, M.A., F.R.S. And Formulæ for Calculating Girders, &c. The whole arranged and edited by W. HUMBER, Assoc. Inst. C.E., Author of "A Complete and Practical Treatise on Cast and Wrought-Iron Bridge Construction," &c. 8vo, 400 pp., with 19 large Plates, and numerous woodcuts, *18s.* cloth.

"The book is undoubtedly worthy of the highest commendation."—***Mining Journal.***

"The best book on the subject which has yet appeared. . . . . We know of no work that so completely fulfils its mission."—***English Mechanic.***

"The standard treatise upon this particular subject."—***Engineer.***

## *Tramways and Tram-Traffic.*

TRAMWAYS: their CONSTRUCTION and WORKING. Containing a Comprehensive History of the System; an exhaustive Analysis of the Various Modes of Traction, including Horse Power, Steam, Heated Water, and Compressed Air; a Description of the varieties of Rolling Stock; and ample Details of Cost and Working Expenses, with Special reference to the Tramways of the United Kingdom. By D. KINNEAR CLARK, M. I. C. E., Author of 'Railway Machinery,' &c., in one vol. 8vo, with numerous illustrations and thirteen folding plates. [*Nearly ready.*

## *Iron and Steel.*

'IRON AND STEEL': a Work for the Forge, Foundry, Factory, and Office. Containing Ready, Useful, and Trustworthy Information for Ironmasters and their Stocktakers; Managers of Bar, Rail, Plate, and Sheet Rolling Mills; Iron and Metal Founders; Iron Ship and Bridge Builders; Mechanical, Mining, and Consulting Engineers; Architects, Contractors, Builders, and Professional Draughtsmen. By CHARLES HOARE, Author of 'The Slide Rule,' &c. Eighth Edition. Revised throughout and considerably enlarged. With folding Scales of "Foreign Measures compared with the English Foot," and "fixed Scales of Squares, Cubes, and Roots, Areas, Decimal Equivalents, &c." Oblong, 32mo, leather elastic-band, 6*s*.

"We cordially recommend this book to those engaged in considering the details of all kinds of iron and steel works. . . . . It has been compiled with care and accuracy. . . . . Many useful rules and hints are given for lessening the amount of arithmetical labour which is always more or less necessary in arranging iron and steel work of all kinds, and a great quantity of useful tables for preparing estimates of weights, dimensions, strengths of structures, costs of work, &c., will be found in Mr. Hoare's book.—*Naval Science.*

## *Weale's Engineer's Pocket-Book.*

THE ENGINEER'S, ARCHITECT'S, and CONTRACTOR'S POCKET-BOOK (LOCKWOOD & Co.'s; formerly WEALE'S). Published Annually. In roan tuck, gilt edges, with 10 Copper-Plates and numerous Woodcuts. 6*s*.

"A vast amount of really valuable matter condensed into the small dimensions of a book which is, in reality, what it professes to be—a pocket-book. . . . We cordially recommend the book.—*Colliery Guardian.*

"It contains a large amount of information peculiarly valuable to those for whose use it is compiled. We cordially commend it to the engineering and architectural professions generally."—*Mining Journal.*

## *Iron Bridges, Girders, Roofs, &c.*

A TREATISE on the APPLICATION of IRON to the CONSTRUCTION of BRIDGES, GIRDERS, ROOFS, and OTHER WORKS; showing the Principles upon which such Structures are Designed, and their Practical Application. Especially arranged for the use of Students and Practical Mechanics, all Mathematical Formulæ and Symbols being excluded. By FRANCIS CAMPIN, C.E. Second Edition revised and corrected. With numerous Diagrams. 12mo, cloth boards, 3*s*.

"Invaluable to those who have not been educated in mathematics."—*Colliery Guardian.*

"Remarkably accurate and well written."—*Artizan.*

## *Pioneer Engineering.*

PIONEER ENGINEERING. A Treatise on the Engineering Operations connected with the Settlement of Waste Lands in New Countries. By EDWARD DOBSON, Assoc. Inst. C.E., Author of "The Art of Building," &c. With numerous Plates and Wood Engravings. Crown 8vo, 10*s.* 6*d.*, cloth. [*Just published.*

"A most useful handbook to engineering pioneers."—*Iron.*

"The author's experience has been turned to good account, and the book is likely to be of considerable service to pioneer engineers."—*Building News.*

## *New Iron Trades' Companion.*

THE IRON AND METAL TRADES' COMPANION: Being a Calculator containing a Series of Tables upon a new and comprehensive plan for expeditiously ascertaining the value of any goods bought or sold by weight, from 1*s.* per cwt. to 112*s.* per cwt., and from one farthing per pound to one shilling per pound. Each Table extends from one pound to 100 tons; to which are appended Rules on Decimals, Square and Cube Root, Mensuration of Superficies and Solids, &c.; also Tables of Weights of Materials, and other Useful Memoranda. By THOMAS DOWNIE. Strongly bound in leather, 396 pp., 9*s.*

"A most useful set of tables, and will supply a want, for nothing like them before existed."—*Building News.*

"Will save the possessor the trouble of making numerous intricate calculations. Although specially adapted to the iron and metal trades, the tables contained in this handy little companion will be found useful in every other business in which merchandise is bought and sold by weight."—*Railway News.*

## *Sanitary Work.*

SANITARY WORK IN THE SMALLER TOWNS AND IN VILLAGES. Comprising:—1. Some of the more Common Forms of Nuisance and their Remedies; 2. Drainage; 3. Water Supply. A useful book for Members of Local Boards and Rural Sanitary Authorities, Health Officers, Engineers, Surveyors, Builders, and Contractors. By CHARLES SLAGG, Assoc. Inst. C.E. Crown 8vo, 5*s.*, cloth.

"Mr. Slagg has brought together much valuable information, and has a happy lucidity of expression; and he has been industrious in collecting data."—*Athenæum.*

"This is a very useful book, and may be safely recommended. . . . . The author, Mr. Charles Slagg, has had practical experience in the works of which he treats. There is a great deal of work required to be done in the smaller towns and villages, and this little volume will help those who are willing to do it."—*Builder.*

## *Sanitary Engineering.*

WHOLESOME HOUSES: being an exposition of the Banner System of Sanitation. By EDWARD GREGSON BANNER, C.E. New and enlarged edition (25th thousand), illustrated with numerous Wood Engravings. Crown 8vo, sewed 6*d.*, cloth 1*s.* [*Just published.*

## *Steam Engine.*

STEAM AND THE STEAM ENGINE, Stationary and Portable, an Elementary Treatise on. Being an Extension of Mr. John Sewell's Treatise on Steam. By D. KINNEAR CLARK, C.E., M.I.C.E., Author of "Railway Locomotives," &c. With Illustrations. 12mo, 4*s.*, cloth.

"Every essential part of the subject is treated of competently, and in a popular style."—*Iron.*

## *Strains.*

THE STRAINS ON STRUCTURES OF IRONWORK; with Practical Remarks on Iron Construction. By F. W. SHEILDS, M. Inst. C.E. Second Edition, with 5 plates. Royal 8vo, 5*s.* cloth.

CONTENTS.—Introductory Remarks; Beams Loaded at Centre; Beams Loaded at unequal distances between supports; Beams uniformly Loaded; Girders with triangular bracing Loaded at centre; Ditto, Loaded at unequal distances between supports; Ditto, uniformly Loaded; Calculation of the Strains on Girders with triangular Basings; Cantilevers; Continuous Girders; Lattice Girders; Girders with Vertical Struts and Diagonal Ties; Calculation of the Strains on Ditto; Bow and String Girders; Girders of a form not belonging to any regular figure; Plate Girders; Apportionments of Material to Strain; Comparison of different Girders; Proportion of Length to Depth of Girders; Character of the Work; Iron Roofs.

## *Construction of Iron Beams, Pillars, &c.*

IRON AND HEAT, Exhibiting the Principles concerned in the Construction of Iron Beams, Pillars, and Bridge Girders, and the Action of Heat in the Smelting Furnace. By JAMES ARMOUR, C.E. Woodcuts, 12mo, cloth boards, 3*s.* 6*d.*; cloth limp, 2*s.* 6*d.*

"A very useful and thoroughly practical little volume, in every way deserving of circulation amongst working men."—*Mining Journal.*

"No ironworker who wishes to acquaint himself with the principles of his own trade can afford to be without it."—*South Durham Mercury.*

## *Power in Motion.*

POWER IN MOTION: Horse Power, Motion, Toothed Wheel Gearing, Long and Short Driving Bands, Angular Forces, &c. By JAMES ARMOUR, C.E. With 73 Diagrams. 12mo, cloth boards, 3*s.* 6*d.*

"Numerous illustrations enable the author to convey his meaning as explicitly as it is perhaps possible to be conveyed. The value of the theoretic and practical knowledge imparted cannot well be over estimated."—*Newcastle Weekly Chronicle.*

## *Metallurgy of Iron.*

A TREATISE ON THE METALLURGY OF IRON: containing Outlines of the History of Iron Manufacture, Methods of Assay, and Analyses of Iron Ores, Processes of Manufacture of Iron and Steel, &c. By H. BAUERMAN, F.G.S., Associate of the Royal School of Mines. With numerous Illustrations. Fourth Edition, revised and much enlarged. 12mo, cloth boards, 5*s.* 6*d.*

"Carefully written, it has the merit of brevity and conciseness, as to less important points, while all material matters are very fully and thoroughly entered into."—*Standard.*

## *Trigonometrical Surveying.*

AN OUTLINE OF THE METHOD OF CONDUCTING A TRIGONOMETRICAL SURVEY, for the Formation of Geographical and Topographical Maps and Plans, Military Reconnaissance, Levelling, &c., with the most useful Problems in Geodesy and Practical Astronomy, and Formulæ and Tables for Facilitating their Calculation. By LIEUT-GENERAL FROME, R.E., late Inspector-General of Fortifications, &c. Fourth Edition, Enlarged, thoroughly Revised, and partly Re-written. By CAPTAIN CHARLES WARREN, R.E., F.G.S. With 19 Plates and 115 Woodcuts, royal 8vo, 16*s.* cloth.

## *Practical Tunnelling.*

PRACTICAL TUNNELLING: Explaining in detail the Setting out of the Works, Shaft-sinking and Heading-Driving, Ranging the Lines and Levelling under Ground, Sub-Excavating, Timbering, and the Construction of the Brickwork of Tunnels with the amount of labour required for, and the Cost of, the various portions of the work. By Frederick Walter Simms, M. Inst. C.E., author of "A Treatise on Levelling." Third Edition, Revised and Extended, with additional chapters illustrating the Recent Practice ot Tunnelling as exemplified by the St. Gothard, Mont Cenis, and other modern works, by D. Kinnear Clark, M. Inst. C.E. Imp. 8vo, with 21 Folding Plates and numerous Wood Engravings, 30*s.*, cloth.

"It is the only practical treatise on the great art of tunnelling. Mr. Clark's work brings the exigencies of tunnel enterprise up to our own time. The great length of modern tunnels has led to a new difficulty in the art, which the last generation was ignorant of, namely, the difficulty of ventilation. In Mr. Clark's supplement we find this branch of the subject has been fully considered. Mr. Clark's additional chapters on the Mont Cenis and St. Gothard Tunnels contain minute and valuable experiences and data relating to the method of excavation by compressed air, the heading operations, rock-boring machinery, process of enlargement, ventilation in course of construction by compressed air, labour and cost, &c."—*Building News.*

"The estimation in which Mr. Simms' book on tunnelling has been held for over thirty years cannot be more truly expressed than in the words of the late Professor Rankine:—'The best source of information on the subject of tunnels is Mr. F. W. Simms' work on "Practical Tunnelling."'—*The Architect.*

## *Levelling.*

A TREATISE on the PRINCIPLES and PRACTICE of LEVELLING; showing its Application to Purposes of Railway and Civil Engineering, in the Construction of Roads; with Mr. Telford's Rules for the same. By Frederick W. Simms, F.G.S., M. Inst. C.E. Sixth Edition, very carefully revised, with the addition of Mr. Law's Practical Examples for Setting out Railway Curves, and Mr. Trautwine's Field Practice of Laying out Circular Curves. With 7 Plates and numerous Woodcuts. 8vo, 8*s.* 6*d.* cloth. ⁂ Trautwine on Curves, separate, 5*s.*

"One of the most important text-books for the general surveyor, and there is scarcely a question connected with levelling for which a solution would be sought that would be satisfactorily answered by consulting the volume."—*Mining Journal.*

"The text-book on levelling in most of our engineering schools and colleges."—*Engineer.*

## *The High-Pressure Steam Engine.*

THE HIGH-PRESSURE STEAM ENGINE; an Exposition of its Comparative Merits, and an Essay towards an Improved System of Construction, adapted especially to secure Safety and Economy. By Dr. Ernst Alban, Practical Machine Maker, Plau, Mecklenberg. Translated from the German, with Notes, by Dr. Pole, F.R.S., M. Inst. C.E., &c. &c. With 28 fine Plates, 8vo, 16*s.* 6*d.* cloth.

"A work like this, which goes thoroughly into the examination of the high-pressure engine, the boiler, and its appendages, &c., is exceedingly useful, and deserves a place in every scientific library."—*Steam Shipping Chronicle.*

## *Reynolds' Locomotive-Engine Driving.*

LOCOMOTIVE-ENGINE DRIVING: a Practical Manual for Engineers in charge of Locomotive Engines. By MICHAEL REYNOLDS, Inspector, Locomotive and Carriage Department, London, Brighton, and South Coast Railway. Second Edition. With Illustrations. Crown 8vo, 4*s*. 6*d*., cloth. [*Just published.*

"Mr. Reynolds has supplied a want, and has supplied it well. We can confidently recommend the book not only to the practical driver, but to every one who takes an interest in the performance of locomotive engines."—*The Engineer.*

"The work is as novel as it is useful, and if drivers and firemen will but take as much pains in reading it as the author has in writing it, there can be no question as to the benefit they will derive."—*English Mechanic.*

"Mr. Reynolds has opened a new chapter in the literature of the day. This admirable practical treatise, of the practical utility of which we have to speak in terms of warm commendation."—*Athenæum.*

## *Hydraulics.*

HYDRAULIC TABLES, CO-EFFICIENTS, and FORMULÆ for finding the Discharge of Water from Orifices, Notches, Weirs, Pipes, and Rivers. With New Formulæ, Tables, and General Information on Rain-fall, Catchment-Basins, Drainage, Sewerage, Water Supply for Towns and Mill Power. By JOHN NEVILLE, Civil Engineer, M.R.I.A. Third Edition, carefully revised, with considerable Additions. Numerous Illustrations. Cr. 8vo, 14*s*. cloth.

"Undoubtedly an exceedingly useful and elaborate compilation."—*Iron.*

"Alike valuable to students and engineers in practice."—*Mining Journal.*

## *Strength of Cast Iron, &c.*

A PRACTICAL ESSAY on the STRENGTH of CAST IRON and OTHER METALS. By the late THOMAS TREDGOLD, Mem. Inst. C.E., Author of "Elementary Principles of Carpentry," &c. Fifth Edition, Edited by EATON HODGKINSON, F.R.S.; to which are added EXPERIMENTAL RESEARCHES on the STRENGTH and OTHER PROPERTIES of CAST IRON. By the EDITOR. The whole Illustrated with 9 Engravings and numerous Woodcuts. 8vo, 12*s*. cloth.

⁂ HODGKINSON ON CAST IRON, separately. Price 6*s*. cloth.

## *Steam Boilers.*

A TREATISE ON STEAM BOILERS: their Strength, Construction, and Economical Working. By R. WILSON, A.I.C.E. Fourth Edition. 12mo, 6*s*., cloth.

"The best work on boilers which has come under our notice."—*Engineering.*

"The best treatise that has ever been published on steam boilers."—*Engineer.*

## *Tables of Curves.*

TABLES OF TANGENTIAL ANGLES and MULTIPLES for setting out Curves from 5 to 200 Radius. By ALEXANDER BEAZELEY, M. Inst. C.E. Printed on 48 Cards, and sold in a cloth box, waistcoat-pocket size, 3*s*. 6*d*.

"Each table is printed on a small card, which, being placed on the theodolite, leaves the hands free to manipulate the instrument—no small advantage as regards the rapidity of work. They are clearly printed, and compactly fitted into a small case for the pocket—an arrangement that will recommend them to all practical men."—*Engineer.*

"Very handy: a man may know that all his day's work must fall on two of these cards, which he puts into his own card-case, and leaves the rest behind."—*Athenæum.*

## *Slate and Slate Quarrying.*

A TREATISE ON SLATE AND SLATE QUARRYING, Scientific, Practical, and Commercial. By D. C. DAVIES, F.G.S., Mining Engineer, &c. With numerous Illustrations and Folding Plates. Crown 8vo, *6s.*, cloth. [*Just published.*

"A useful and practical hand-book on an important industry."—*Engineering.*

"A useful embodiment of practical information derived from original sources, combined with a digest of everything that has already appeared likely to be of interest."—*Building News.*

"There is no other book which contains so much information concerning the procedure observed in taking quarries, the processes employed in working them, and such full statistics of the present and past position of the great slate trade of Wales."—*The Architect.*

## *Earthwork.*

EARTHWORK TABLES, showing the Contents in Cubic Yards of Embankments, Cuttings, &c., of Heights or Depths up to an average of 80 feet. By JOSEPH BROADBENT, C. E., and FRANCIS CAMPIN, C.E. Cr. 8vo, oblong, *5s.* cloth.

"The way in which accuracy is attained, by a simple division of each cross section into three elements, two of which are constant and one variable, is ingenious."—*Athenæum.*

"Cannot fail to come into general use."—*Mining Journal.*

## *Surveying (Land and Marine).*

LAND AND MARINE SURVEYING, in Reference to the Preparation of Plans for Roads and Railways, Canals, Rivers, Towns' Water Supplies, Docks and Harbours; with Description and Use of Surveying Instruments. By W. DAVIS HASKOLL, C.E. 8vo, *12s. 6d.* cloth, with 14 folding Plates, and numerous Woodcuts.

"A most useful and well arranged book for the aid of a student."—*Builder.*

"Cannot fail to prove of the utmost practical utility, and may be safely recommended to all students who aspire to become clean and expert surveyors."—*Mining Journal.*

## *Engineering Fieldwork.*

THE PRACTICE OF ENGINEERING FIELDWORK, applied to Land and Hydraulic, Hydrographic, and Submarine Surveying and Levelling. Second Edition, revised, with considerable additions, and a Supplementary Volume on WATER-WORKS, SEWERS, SEWAGE, and IRRIGATION. By W. DAVIS HASKOLL, C.E. Numerous folding Plates. Demy 8vo, 2 vols. in one, cloth boards, *1l. 1s.* (published at *2l. 4s.*)

## *Mining, Surveying and Valuing.*

THE MINERAL SURVEYOR AND VALUER'S COMPLETE GUIDE, comprising a Treatise on Improved Mining Surveying, with new Traverse Tables; and Descriptions of Improved Instruments; also an Exposition of the Correct Principles of Laying out and Valuing Home and Foreign Iron and Coal Mineral Properties. By WILLIAM LINTERN, Mining and Civil Engineer. With four Plates of Diagrams, Plans, &c., 12mo, *4s.*, cloth.

"Contains much valuable information given in a small compass, and which, as far as we have tested it, is thoroughly trustworthy."—*Iron and Coal Trades Review.*

⁂ The above, bound with THOMAN'S TABLES. (See page 22). Price *7s. 6d.*, cloth.

## *Fire Engineering.*

FIRES, FIRE-ENGINES, AND FIRE BRIGADES. With a History of Fire-Engines, their Construction, Use, and Management; Remarks on Fire-Proof Buildings, and the Preservation of Life from Fire; Statistics of the Fire Appliances in English Towns; Foreign Fire Systems; Hints on Fire Brigades, &c., &c. By CHARLES F. T. YOUNG, C.E. With numerous Illustrations, handsomely printed, 544 pp., demy 8vo, 1*l.* 4*s.* cloth.

"We can most heartily commend this book. . . . . It is really the only English work we now have upon the subject."—*Engineering.*

"We strongly recommend the book to the notice of all who are in any way interested in fires, fire-engines, or fire-brigades."—*Mechanics' Magazine.*

## *Manual of Mining Tools.*

MINING TOOLS. For the use of Mine Managers, Agents, Mining Students, &c. By WILLIAM MORGANS, Lecturer on Practical Mining at the Bristol School of Mines. Volume of Text. 12mo. With an Atlas of Plates, containing 235 Illustrations. 4to. Together, 9*s.* cloth boards.

"Students in the Science of Mining, and not only they, but subordinate officials in mines, and even Overmen, Captains, Managers, and Viewers may gain practical knowledge and useful hints by the study of Mr. Morgans' Manual."—*Colliery Guardian.*

"A very valuable work, which will tend materially to improve our mining literature."—*Mining Journal.*

## *Common Sense for Gas-Users.*

COMMON SENSE FOR GAS-USERS: a Catechism of Gas-Lighting for Householders, Gasfitters, Millowners, Architects, Engineers, &c., &c. By ROBERT WILSON, C.E., Author of "A Treatise on Steam Boilers." Second Edition. Crown 8vo, sewed, with Folding Plates and Wood Engravings, 2*s.* 6*d.* [*Just published.*

## *Gas and Gasworks.*

A TREATISE on GASWORKS and the PRACTICE of MANUFACTURING and DISTRIBUTING COAL GAS. By SAMUEL HUGHES, C.E. Fourth Edition, revised by W. RICHARDS, C.E. With 68 Woodcuts, 12mo, 4*s.*, cloth boards.

## *Waterworks for Cities and Towns.*

WATERWORKS for the SUPPLY of CITIES and TOWNS, with a Description of the Principal Geological Formations of England as influencing Supplies of Water. By SAMUEL HUGHES, F.G.S., Civil Engineer. New and enlarged edition, 12mo, with numerous Illustrations, 5*s.*, cloth boards.

"One of the most convenient, and at the same time reliable works on a subject, the vital importance of which cannot be over-estimated."—*Bradford Observer.*

## *Coal and Coal Mining.*

COAL AND COAL MINING: a Rudimentary Treatise on. By WARINGTON W. SMYTH, M.A., F.R.S., &c., Chief Inspector of the Mines of the Crown and of the Duchy of Cornwall. New edition, revised and corrected. 12mo, with numerous Illustrations, 4*s.* 6*d.*, cloth boards.

"Every portion of the volume appears to have been prepared with much care, and as an outline is given of every known coal-field in this and other countries, as well as of the two principal methods of working, the book will doubtless interest a very large number of readers."—*Mining Journal.*

## *Roads and Streets.*

THE CONSTRUCTION OF ROADS AND STREETS. In Two Parts. I. The Art of Constructing Common Roads. By HENRY LAW, C.E. Revised and Condensed by D. KINNEAR CLARK, C.E.—II. Recent Practice in the Construction of Roads and Streets: including Pavements of Stone, Wood, and Asphalte. By D. KINNEAR CLARK, C.E., M.I.C.E., Author of "Railway Machinery," "A Manual of Rules, Tables, and Data," &c. With numerous Illustrations. 12mo, 5*s.*, cloth. [*Just published.*

"A book which every borough surveyor and engineer must possess, and which will be of considerable service to architects, builders, and property owners generally."—*Building News.*

"The volume is suggestive, and will be an acquisition not only to engineers but to the greater number of people in this country on whom devolves the administration of roads as a part of the system of local government."—*The Architect.*

"To highway and town surveyors this book will have the utmost value, and as containing the largest amount of information in the shortest space and at the lowest price, we may predict for it a wide circulation."—*Journal of Gas Lighting.*

## *Field-Book for Engineers.*

THE ENGINEER'S, MINING SURVEYOR'S, and CONTRACTOR'S FIELD-BOOK. By W. DAVIS HASKOLL, C.E. Third Edition, enlarged, consisting of a Series of Tables, with Rules, Explanations of Systems, and Use of Theodolite for Traverse Surveying and Plotting the Work with minute accuracy by means of Straight Edge and Set Square only; Levelling with the Theodolite, Casting out and Reducing Levels to Datum, and Plotting Sections in the ordinary manner; Setting out Curves with the Theodolite by Tangential Angles and Multiples with Right and Left-hand Readings of the Instrument; Setting out Curves without Theodolite on the System of Tangential Angles by Sets of Tangents and Offsets; and Earthwork Tables to 80 feet deep, calculated for every 6 inches in depth. With numerous wood-cuts, 12mo, 12*s.* cloth.

"The book is very handy, and the author might have added that the separate tables of sines and tangents to every minute will make it useful for many other purposes, the genuine traverse tables existing all the same."—*Athenæum.*

"A very useful work for the practical engineer and surveyor."—*Railway News.*

"The work forms a handsome pocket volume, and cannot fail, from its portability and utility, to be extensively patronised by the engineering profession."—*Mining Journal.*

"We strongly recommend it to all classes of surveyors."—*Colliery Guardian.*

## *Earthwork, Measurement and Calculation of.*

A MANUAL on EARTHWORK. By ALEX. J. S. GRAHAM, C.E., Resident Engineer, Forest of Dean Central Railway. With numerous Diagrams. 18mo, 2*s.* 6*d.* cloth.

"As a really handy book for reference, we know of no work equal to it; and the railway engineers and others employed in the measurement and calculation of earthwork will find a great amount of practical information very admirably arranged, and available for general or rough estimates, as well as for the more exact calculations required in the engineers' contractor's offices."—*Artizan.*

## *Harbours.*

THE DESIGN and CONSTRUCTION of HARBOURS: A Treatise on Maritime Engineering. By THOMAS STEVENSON, F.R.S.E., F.G.S., M.I.C.E. Second Edition, containing many additional subjects, and otherwise generally extended and revised. With 20 Plates and numerous Cuts. Small 4to, 15*s.* cloth.

## *Bridge Construction in Masonry, Timber, & Iron.*

EXAMPLES OF BRIDGE AND VIADUCT CONSTRUCTION OF MASONRY, TIMBER, AND IRON; consisting of 46 Plates from the Contract Drawings or Admeasurement of select Works. By W. DAVIS HASKOLL, C.E. Second Edition, with the addition of 554 Estimates, and the Practice of Setting out Works, illustrated with 6 pages of Diagrams. Imp. 4to, *2l.* *12s.* *6d.* half-morocco.

"One of the very few works extant descending to the level of ordinary routine, and treating on the common every-day practice of the railway engineer. . . . A work of the present nature by a man of Mr. Haskoll's experience, must prove invaluable to hundreds. The tables of estimates appended to this edition will considerably enhance its value."—*Engineering.*

## *Mathematical Instruments, their Construction, &c.*

MATHEMATICAL INSTRUMENTS: THEIR CONSTRUCTION, ADJUSTMENT, TESTING, AND USE; comprising Drawing, Measuring, Optical, Surveying, and Astronomical Instruments. By J. F. HEATHER, M.A., Author of "Practical Plane Geometry," "Descriptive Geometry," &c. Enlarged Edition, for the most part entirely rewritten. With numerous Wood-cuts. 12mo, *5s.* cloth boards.

## *Drawing for Engineers, &c.*

THE WORKMAN'S MANUAL OF ENGINEERING DRAWING. By JOHN MAXTON, Instructor in Engineering Drawing, Royal Naval College, Greenwich, formerly of R. S. N. A., South Kensington. Third Edition, carefully revised. With upwards of 300 Plates and Diagrams. 12mo, cloth, strongly bound, *4s.* *6d.*

"Even accomplished draughtsmen will find in it much that will be of use to them. A copy of it should be kept for reference in every drawing office."—*Engineering.*

"Indispensable for teachers of engineering drawing."—*Mechanics' Magazine.*

## *Oblique Arches.*

A PRACTICAL TREATISE ON THE CONSTRUCTION of OBLIQUE ARCHES. By JOHN HART. Third Edition, with Plates. Imperial 8vo, *8s.* cloth.

## *Oblique Bridges.*

A PRACTICAL and THEORETICAL ESSAY on OBLIQUE BRIDGES, with 13 large folding Plates. By GEO. WATSON BUCK, M. Inst. C.E. Second Edition, corrected by W. H. BARLOW, M. Inst. C.E. Imperial 8vo, *12s.* cloth.

"The standard text-book for all engineers regarding skew arches, is Mr. Buck's treatise, and it would be impossible to consult a better."—*Engineer.*

## *Pocket-Book for Marine Engineers.*

A POCKET BOOK FOR MARINE ENGINEERS. Containing useful Rules and Formulæ in a compact form. By FRANK PROCTOR, A.I.N.A. Second Edition, revised and enlarged. Royal 32mo, leather, gilt edges, with strap, *4s.*

"We recommend it to our readers as going far to supply a long-felt want."—*Naval Science.*

"A most useful companion to all marine engineers."—*United Service Gazette.*

"Scarcely anything required by a naval engineer appears to have been forgotten."—*Iron.*

## *Grantham's Iron Ship-Building, enlarged.*

ON IRON SHIP-BUILDING; with Practical Examples and Details. Fifth Edition. Imp. 4to, boards, enlarged from 24 to 40 Plates (21 quite new), including the latest Examples. Together with separate Text, 12mo, cloth limp, also considerably enlarged. By JOHN GRANTHAM, M. Inst. C.E., &c. *2l. 2s.* complete.

"A thoroughly practical work, and every question of the many in relation to iron shipping which admit of diversity of opinion, or have various and conflicting personal interests attached to them, is treated with sober and impartial wisdom and good sense. . . . . As good a volume for the instruction of the pupil or student of iron naval architecture as can be found in any language."—*Practical Mechanics' Journal.*

"A very elaborate work. . . . It forms a most valuable addition to the history of iron shipbuilding, while its having been prepared by one who has made the subject his study for many years, and whose qualifications have been repeatedly recognised, will recommend it as one of practical utility to all interested in shipbuilding."—*Army and Navy Gazette.*

"Mr. Grantham's work is of great interest. . . . It is also valuable as a record of the progress of iron shipbuilding. . . . It will, we are confident, command an extensive circulation among shipbuilders in general. . . . By order of the Board of Admiralty, the work will form the text-book on which the examination in iron shipbuilding of candidates for promotion in the dockyards will be mainly based."—*Engineering.*

## *Weale's Dictionary of Terms.*

A DICTIONARY of TERMS used in ARCHITECTURE, BUILDING, ENGINEERING, MINING, METALLURGY, ARCHÆOLOGY, the FINE ARTS, &c. By JOHN WEALE. Fifth Edition, revised and corrected by ROBERT HUNT, F.R.S., Keeper of Mining Records, Editor of "Ure's Dictionary of Arts," &c. 12mo, cloth boards, *6s.*

"A book for the enlightenment of those whose memory is treacherous or education deficient in matters scientific and industrial. The additions made of modern discoveries and knowledge are extensive. The result is 570 pages of concentrated essence of elementary knowledge, admirably and systematically arranged, and presented in neat and handy form."—*Iron.*

"The best small technological dictionary in the language."—*Architect.*

"A comprehensive and accurate compendium. Author, editor, and publishers deserve high commendations for producing such a useful work. We can warmly recommend such a dictionary as a standard work of reference to our subscribers. Every ironmonger should procure it—no engineer should be without it—builders and architects must admire it—metallurgists and archæologists would profit by it."—*Ironmonger.*

"The absolute accuracy of a work of this character can only be judged of after extensive consultation, and from our examination it appears very correct and very complete."—*Mining Journal.*

"There is no need now to speak of the excellence of this work; it received the approval of the community long ago. Edited now by Mr. Robert Hunt, and published in a cheap, handy form, it will be of the utmost service as a book of reference scarcely to be exceeded in value."—*Scotsman.*

## *Steam.*

THE SAFE USE OF STEAM: containing Rules for Unprofessional Steam Users. By an ENGINEER. Third Edition. 12mo. Sewed, *6d.*

N. B.—*This little work should be in the hands of every person having to deal with a Steam Engine of any kind.*

"If steam-users would but learn this little book by heart, and then hand it to their stokers to do the same, and see that the latter do it, boiler explosions would become sensations by their rarity."—*English Mechanic.*

# ARCHITECTURE, &c.

## *Construction.*

THE SCIENCE of BUILDING: An Elementary Treatise on the Principles of Construction. By E. **WYNDHAM TARN**, M.A., Architect. With 47 Wood Engravings. Demy 8vo. 8*s.* 6*d.* cloth.

"A very valuable book, which we strongly recommend to all students."—*Builder.*

"No architectural student should be without this hand-book."—*Architect.*

"An able digest of information which is only to be found scattered through various works."—*Engineering.*

## *Beaton's Pocket Estimator.*

THE POCKET ESTIMATOR FOR THE BUILDING TRADES, being an easy method of estimating the various parts of a Building collectively, more especially applied to Carpenters' and Joiners' work, priced according to the present value of material and labour. By A. C. **BEATON**, Author of 'Quantities and Measurements.' Second Edition. Carefully revised. 33 Woodcuts. Leather. Waistcoat-pocket size. 1*s.* 6*d.*

## *Beaton's Builders' and Surveyors' Technical Guide.*

THE POCKET TECHNICAL GUIDE AND MEASURER FOR BUILDERS AND SURVEYORS: containing a Complete Explanation of the Terms used in Building Construction, Memoranda for Reference, Technical Directions for Measuring Work in all the Building Trades, &c., &c. By A. C. **BEATON**. With 19 Woodcuts. Leather. Waistcoat-pocket size. 1*s.* 6*d.*

## *Villa Architecture.*

A HANDY BOOK of VILLA ARCHITECTURE; being a Series of Designs for Villa Residences in various Styles. With Detailed Specifications and Estimates. By C. **WICKES**, Architect, Author of "The Spires and Towers of the Mediæval Churches of England," &c. Complete in 1 vol. 61 Plates. 4to, 2*l.* 2*s.* half morocco.

⁂ A SELECTION FROM THE ABOVE, containing 30 Designs, with Detailed Specifications, Estimates, &c. 21*s.* half morocco.

"The whole of the designs bear evidence of their being the work of an artistic architect, and they will prove very valuable and suggestive."—*Building News.*

## *House Painting.*

HOUSE PAINTING, GRAINING, MARBLING, AND SIGN WRITING: a Practical Manual of. With 9 Coloured Plates of Woods and Marbles, and nearly 150 Wood Engravings. By **ELLIS A. DAVIDSON**, Author of 'Building Construction,' &c. Second Edition, carefully revised. 12mo, 6*s.* cloth boards.

"Contains a mass of information of use to the amateur and of value to the practical man."—*English Mechanic.*

"Deals with the practice of painting in all its parts, from the grinding of colours to varnishing and gilding."—*Architect.*

## *Wilson's Boiler and Factory Chimneys.*

BOILER AND FACTORY CHIMNEYS; their Draught-power and Stability, with a chapter on Lightning Conductors. By **ROBERT WILSON**, A.I.C.E., Author of "Treatise on Steam Boilers," &c., &c. Crown 8vo, 3*s.* 6*d.*, cloth. [*Just published.*

"A most valuable book of its kind, full of useful information, definite in statement, and thoroughly practical in treatment."—*The Local Government Chronicle.*

## *A Book on Building.*

A BOOK ON BUILDING, CIVIL AND ECCLESIASTICAL. By Sir Edmund Beckett, Bart., LL.D., Q.C., F.R.A.S., Author of "Clocks and Watches and Bells," &c. Crown 8vo, with Illustrations, 7*s.* 6*d.*, cloth.

"A book which is always amusing and nearly always instructive. Sir E. Beckett will be read for the raciness of his style. We are able very cordially to recommend all persons to read it for themselves. The style throughout is in the highest degree condensed and epigrammatic."—*Times.*

"We commend the book to the thoughtful consideration of all who are interested in the building art."—*Builder.*

"There is hardly a subject connected with either building or repairing on which sensible and practical directions will not be found, the use of which is probably destined to prevent many an annoyance, disappointment, and unnecessary expense."—*Daily News.*

## *Architecture, Ancient and Modern.*

RUDIMENTARY ARCHITECTURE, Ancient and Modern. Consisting of VITRUVIUS, translated by Joseph Gwilt, F.S.A., &c., with 23 fine copper plates; GRECIAN Architecture, by the Earl of Aberdeen; the ORDERS of Architecture, by W. H. Leeds, Esq.; The STYLES of Architecture of Various Countries, by T. Talbot Bury; The PRINCIPLES of DESIGN in Architecture, by E. L. Garbett. In one volume, half-bound (pp. 1,100), copiously illustrated, 12*s.*

⁂ *Sold separately, in two vols., as follows—*

ANCIENT ARCHITECTURE. Containing Gwilt's Vitruvius and Aberdeen's Grecian Architecture. Price 6*s.* half-bound.

N.B.—*This is the only edition of VITRUVIUS procurable at a moderate price.*

MODERN ARCHITECTURE. Containing the Orders, by Leeds; The Styles, by Bury; and Design, by Garbett. 6*s.* half-bound.

## *The Young Architect's Book.*

HINTS TO YOUNG ARCHITECTS. By George Wightwick, Architect, Author of "The Palace of Architecture," &c. &c. New Edition, revised and enlarged. By G. Huskisson Guillaume, Architect. Numerous illustrations. 12mo, cloth boards, 4*s.*

"Will be found an acquisition to pupils, and a copy ought to be considered as necessary a purchase as a box of instruments."—*Architect.*

"Contains a large amount of information, which young architects will do well to acquire, if they wish to succeed in the everyday work of their profession."—*English Mechanic.*

## *Drawing for Builders and Students.*

PRACTICAL RULES ON DRAWING for the OPERATIVE BUILDER and YOUNG STUDENT in ARCHITECTURE. By George Pyne, Author of a "Rudimentary Treatise on Perspective for Beginners." With 14 Plates, 4to, 7*s.* 6*d.* boards.

## *Builder's and Contractor's Price Book.*

LOCKWOOD & CO.'S BUILDER'S AND CONTRACTOR'S PRICE BOOK for 1878, containing the latest prices of all kinds of Builders' Materials and Labour, and of all Trades connected with Building, &c., &c. The whole revised and edited by Francis T. W. Miller, Architect and Surveyor. Fcap. 8vo, strongly half-bound, 4*s.*

## *Handbook of Specifications.*

THE HANDBOOK OF SPECIFICATIONS; or, Practical Guide to the Architect, Engineer, Surveyor, and Builder, in drawing up Specifications and Contracts for Works and Constructions. Illustrated by Precedents of Buildings actually executed by eminent Architects and Engineers. Preceded by a Preliminary Essay, and Skeletons of Specifications and Contracts, &c., &c. By Professor Thomas L. Donaldson, M.I.B.A. With A Review of the Law of Contracts. By W. Cunningham Glen, of the Middle Temple. With 33 Lithographic Plates, 2 vols., 8vo, 2*l.* 2*s.*

"In these two volumes of 1,100 pages (together), forty-four specifications of executed works are given, including the specifications for parts of the new Houses of Parliament, by Sir Charles Barry, and for the new Royal Exchange, by Mr. Tite, M.P. Donaldson's Handbook of Specifications must be bought by all architects."—*Builder.*

## *Taylor and Cresy's Rome.*

THE ARCHITECTURAL ANTIQUITIES OF ROME. By the late G. L. Taylor, Esq., F.S.A., and Edward Cresy, Esq. New Edition, thoroughly revised, and supplemented under the editorial care of the Rev. Alexander Taylor, M.A. (son of the late G. L. Taylor, Esq.), Chaplain of Gray's Inn. This is the only book which gives on a large scale, and with the precision of architectural measurement, the principal Monuments of Ancient Rome in plan, elevation, and detail. Large folio, with 130 Plates, half-bound, 3*l.* 3*s.*

⁂ Originally published in two volumes, folio, at 18*l.* 18*s.*

## *Specifications for Practical Architecture.*

SPECIFICATIONS FOR PRACTICAL ARCHITECTURE: A Guide to the Architect, Engineer, Surveyor, and Builder; with an Essay on the Structure and Science of Modern Buildings. By Frederick Rogers, Architect. With numerous Illustrations. Demy 8vo, 15*s.*, cloth. (Published at 1*l.* 10*s.*)

⁂ A volume of specifications of a practical character being greatly required, and the old standard work of Alfred Bartholomew being out of print, the author, on the basis of that work, has produced the above. He has also inserted specifications of works that have been erected in his own practice.

## *The House-Owner's Estimator.*

THE HOUSE-OWNER'S ESTIMATOR; or, What will it Cost to Build, Alter, or Repair? A Price-Book adapted to the Use of Unprofessional People as well as for the Architectural Surveyor and Builder. By the late James D. Simon, A.R.I.B.A. Edited and Revised by Francis T. W. Miller, Surveyor. With numerous Illustrations. Second Edition, with the prices carefully revised to 1875. Crown 8vo, cloth, 3*s.* 6*d.*

"In two years it will repay its cost a hundred times over."—*Field.*

"A very handy book for those who want to know what a house will cost to build, alter, or repair."—*English Mechanic.*

"Especially valuable to non-professional readers."—*Mining Journal.*

## *Useful Text-Book for Architects.*

THE ARCHITECT'S GUIDE: Being a Text-book of Useful Information for Architects, Engineers, Surveyors, Contractors, Clerks of Works, &c., &c. By Frederick Rogers, Architect, Author of 'Specifications for Practical Architecture,' &c. With numerous Illustrations. Crown 8vo, 6*s.* cloth.

# CARPENTRY, TIMBER, MECHANICS.

◆

## *Tredgold's Carpentry, new and cheaper Edition.*

THE ELEMENTARY PRINCIPLES OF CARPENTRY: a Treatise on the Pressure and Equilibrium of Timber Framing, the Resistance of Timber, and the Construction of Floors, Arches, Bridges, Roofs, Uniting Iron and Stone with Timber, &c. To which is added an Essay on the Nature and Properties of Timber, &c., with Descriptions of the Kinds of Wood used in Building; also numerous Tables of the Scantlings of Timber for different purposes, the Specific Gravities of Materials, &c. By THOMAS TREDGOLD, C.E. Edited by PETER BARLOW, F.R.S. Fifth Edition, corrected and enlarged. With 64 Plates (11 of which now first appear in this edition), Portrait of the Author, and several Woodcuts. In 1 vol., 4to, published at 2*l.* 2*s.*, reduced to 1*l.* 5*s.*, cloth.

"'Tredgold's Carpentry' ought to be in every architect's and every builder's library, and those who do not already possess it ought to avail themselves of the new issue."—*Builder.*

"A work whose monumental excellence must commend it wherever skilful carpentry is concerned. The Author's principles are rather confirmed than impaired by time, and, as now presented, combine the surest base with the most interesting display of progressive science. The additional plates are of great intrinsic value."—*Building News.*

## *Grandy's Timber Tables.*

THE TIMBER IMPORTER'S, TIMBER MERCHANT'S, and BUILDER'S STANDARD GUIDE. By RICHARD E. GRANDY. Comprising:—An Analysis of Deal Standards, Home and Foreign, with comparative Values and Tabular Arrangements for Fixing Nett Landed Cost on Baltic and North American Deals, including all intermediate Expenses, Freight, Insurance, &c., &c.; together with Copious Information for the Retailer and Builder. Second Edition. Carefully revised and corrected. 12mo, 3*s.* 6*d.* cloth.

"Everything it pretends to be: built up gradually, it leads one from a forest to a treenail, and throws in, as a makeweight, a host of material concerning bricks, columns, cisterns, &c.—all that the class to whom it appeals requires."—*English Mechanic.*

"The only difficulty we have is as to what is NOT in its pages. What we have tested of the contents, taken at random, is invariably correct."—*Illustrated Builder's Journal.*

## *Tables for Packing-Case Makers.*

PACKING-CASE TABLES; showing the number of Superficial Feet in Boxes or Packing-Cases, from six inches square and upwards. Compiled by WILLIAM RICHARDSON, Accountant. Second Edition. Oblong 4to, 3*s.* 6*d.*, cloth. [*Just Published.*

"Will save much labour and calculation to packing-case makers and those who use packing-cases."—*Grocer.* "Invaluable labour-saving tables."—*Ironmonger.*

## *Nicholson's Carpenter's Guide.*

THE CARPENTER'S NEW GUIDE; or, BOOK of LINES for CARPENTERS: comprising all the Elementary Principles essential for acquiring a knowledge of Carpentry. Founded on the late PETER NICHOLSON'S standard work. A new Edition, revised by ARTHUR ASHPITEL, F.S.A., together with Practical Rules on Drawing, by GEORGE PYNE. With 74 Plates, 4to, 1*l.* 1*s.* cloth.

## *Dowsing's Timber Merchant's Companion.*

THE TIMBER MERCHANT'S AND BUILDER'S COMPANION; containing New and Copious Tables of the Reduced Weight and Measurement of Deals and Battens, of all sizes, from One to a Thousand Pieces, and the relative Price that each size bears per Lineal Foot to any given Price per Petersburgh Standard Hundred; the Price per Cube Foot of Square Timber to any given Price per Load of 50 Feet; the proportionate Value of Deals and Battens by the Standard, to Square Timber by the Load of 50 Feet; the readiest mode of ascertaining the Price of Scantling per Lineal Foot of any size, to any given Figure per Cube Foot. Also a variety of other valuable information. By WILLIAM DOWSING, Timber Merchant. Third Edition, Revised and Corrected. Crown 8vo, 3*s*. cloth.

"Everything is as concise and clear as it can possibly be made. There can be no doubt that every timber merchant and builder ought to possess it."—*Hull Advertiser.*

## *Timber Freight Book.*

THE TIMBER IMPORTERS' AND SHIPOWNERS' FREIGHT BOOK: Being a Comprehensive Series of Tables for the Use of Timber Importers, Captains of Ships, Shipbrokers, Builders, and all Dealers in Wood whatsoever. By WILLIAM RICHARDSON, Timber Broker. Crown 8vo, 6*s*., cloth.

## *Horton's Measurer.*

THE COMPLETE MEASURER; setting forth the Measurement of Boards, Glass, &c., &c.; Unequal-sided, Square-sided, Octagonal-sided, Round Timber and Stone, and Standing Timber. With just allowances for the bark in the respective species of trees, and proper deductions for the waste in hewing the trees, &c.; also a Table showing the solidity of hewn or eight-sided timber, or of any octagonal-sided column. Compiled for the accommodation of Timber-growers, Merchants, and Surveyors, Stonemasons, Architects, and others. By RICHARD HORTON. Third edition, with considerable and valuable additions, 12mo, strongly bound in leather, 5*s*.

"Not only are the best methods of measurement shown, and in some instances illustrated by means of woodcuts, but the erroneous systems pursued by dishonest dealers are fully exposed. . . . . The work must be considered to be a valuable addition to every gardener's library.—*Garden.*

## *Superficial Measurement.*

THE TRADESMAN'S GUIDE TO SUPERFICIAL MEASUREMENT. Tables calculated from 1 to 200 inches in length, by 1 to 108 inches in breadth. For the use of Architects, Surveyors, Engineers, Timber Merchants, Builders, &c. By JAMES HAWKINGS. Fcp. 3*s*. 6*d*. cloth.

## *Practical Timber Merchant.*

THE PRACTICAL TIMBER MERCHANT, being a Guide for the use of Building Contractors, Surveyors, Builders, &c., comprising useful Tables for all purposes connected with the Timber Trade, Marks of Wood, Essay on the Strength of Timber, Remarks on the Growth of Timber, &c. By W. RICHARDSON. Fcap. 8vo, 3*s*. 6*d*., cloth.

## *The Mechanic's Workshop Companion.*

THE OPERATIVE MECHANIC'S WORKSHOP COMPANION, and THE SCIENTIFIC GENTLEMAN'S PRACTICAL ASSISTANT. By WILLIAM TEMPLETON. Twelfth Edition, with Mechanical Tables for Operative Smiths, Millwrights, Engineers, &c.; and an Extensive Table of Powers and Roots, &c., &c. 11 Plates. 12mo, 5*s.* bound.

"As a text-book of reference, in which mechanical and commercial demands are judiciously met, TEMPLETON'S COMPANION stands unrivalled."—*Mechanics' Magazine.*

"Admirably adapted to the wants of a very large class. It has met with great success in the engineering workshop, as we can testify; and there are a great many men who, in a great measure, owe their rise in life to this little work."—*Building News.*

## *Engineer's Assistant.*

THE ENGINEER'S, MILLWRIGHT'S, and MACHINIST'S PRACTICAL ASSISTANT; comprising a Collection of Useful Tables, Rules, and Data. Compiled and Arranged, with Original Matter, by WILLIAM TEMPLETON. 6th Edition. 18mo, 2*s.* 6*d.* cloth.

"So much varied information compressed into so small a space, and published at a price which places it within the reach of the humblest mechanic, cannot fail to command the sale which it deserves. With the utmost confidence we commend this book to the attention of our readers."—*Mechanics' Magazine.*

"A more suitable present to an apprentice to any of the mechanical trades could not possibly be made."—*Building News.*

## *Designing, Measuring, and Valuing.*

THE STUDENT'S GUIDE to the PRACTICE of MEASURING, and VALUING ARTIFICERS' WORKS; containing Directions for taking Dimensions, Abstracting the same, and bringing the Quantities into Bill, with Tables of Constants, and copious Memoranda for the Valuation of Labour and Materials in the respective Trades of Bricklayer and Slater, Carpenter and Joiner, Painter and Glazier, Paperhanger, &c. With 43 Plates and Woodcuts. Originally edited by EDWARD DOBSON, Architect. New Edition, re-written, with Additions on Mensuration and Construction, and useful Tables for facilitating Calculations and Measurements. By E. WYNDHAM TARN, M.A., 8vo, 10*s.* 6*d.* cloth.

"We have failed to discover anything connected with the building trade, from excavating foundations to bell-hanging, that is not fully treated upon."—*The Artizan.*

"Altogether the book is one which well fulfils the promise of its title-page, and we can thoroughly recommend it to the class for whose use it has been compiled. Mr. Tarn's additions and revisions have much increased the usefulness of the work, and have especially augmented its value to students."—*Engineering.*

## *Plumbing.*

PLUMBING; a text-book to the practice of the art or craft of the plumber. With supplementary chapters upon house-drainage, embodying the latest improvements. By WILLIAM PATON BUCHAN, Sanitary Engineer. 12mo., with about 300 illustrations. 3*s.* 6*d.*, cloth.

"There is no other manual in existence of the plumber's art; and the volume will be welcomed as the work of a practical master of his trade."—*Public Health.*

"The chapters on house-drainage may be usefully consulted, not only by plumbers, but also by engineers and all engaged or interested in house-building."—*Iron.*

"A book containing a large amount of practical information, put together in a very intelligent manner, by one who is well qualified for the task."—*City Press.*

# MATHEMATICS, &c.

## *Gregory's Practical Mathematics.*

MATHEMATICS for PRACTICAL MEN; being a Commonplace Book of Pure and Mixed Mathematics. Designed chiefly for the Use of Civil Engineers, Architects, and Surveyors. Part I. PURE MATHEMATICS—comprising Arithmetic, Algebra, Geometry, Mensuration, Trigonometry, Conic Sections, Properties of Curves. Part II. MIXED MATHEMATICS—comprising Mechanics in general, Statics, Dynamics, Hydrostatics, Hydrodynamics, Pneumatics, Mechanical Agents, Strength of Materials. With an Appendix of copious Logarithmic and other Tables. By OLINTHUS GREGORY, LL.D., F.R.A.S. Enlarged by HENRY LAW, C.E. 4th Edition, carefully revised and corrected by J. R. YOUNG, formerly Professor of Mathematics, Belfast College; Author of "A Course of Mathematics," &c. With 13 Plates. Medium 8vo, 1*l.* 1*s.* cloth.

"As a standard work on mathematics it has not been excelled."—*Artizan.*

"The engineer or architect will here find ready to his hand, rules for solving nearly every mathematical difficulty that may arise in his practice. The rules are in all cases explained by means of examples, in which every step of the process is clearly worked out."—*Builder.*

"One of the most serviceable books to the practical mechanics of the country. . . . . . . In the edition just brought out, the work has again been revised by Professor Young. He has modernised the notation throughout, introduced a few paragraphs here and there, and corrected the numerous typographical errors which have escaped the eyes of the former Editor. The book is now as complete as it is possible to make it. It is an instructive book for the student, and a Textbook for him who having once mastered the subjects it treats of, needs occasionally to refresh his memory upon them."—*Building News.*

## *The Metric System.*

A SERIES OF METRIC TABLES, in which the British Standard Measures and Weights are compared with those of the Metric System at present in use on the Continent. By C. H. DOWLING, C. E. Second Edition, revised and enlarged. 8vo, 10*s.* 6*d.* strongly bound.

"Mr. Dowling's Tables, which are well put together, come just in time as a ready reckoner for the conversion of one system into the other."—*Athenæum.*

"Their accuracy has been certified by Prof. Airy, Astronomer-Royal."—*Builder.*

"Resolution 8.—That advantage will be derived from the recent publication of Metric Tables, by C. H. Dowling, C.E."—*Report of Section F, Brit. Assoc., Bath.*

## *Comprehensive Weight Calculator.*

THE WEIGHT CALCULATOR; being a Series of Tables upon a New and Comprehensive Plan, exhibiting at one Reference the exact Value of any Weight from 1 lb. to 15 tons, at 300 Progressive Rates, from 1 Penny to 168 Shillings per cwt., and containing 186,000 Direct Answers, which with their Combinations, consisting of a single addition (mostly to be performed at sight), will afford an aggregate of 10,266,000 Answers; the whole being calculated and designed to ensure Correctness and promote Despatch. By HENRY HARBEN, Accountant, Sheffield, Author of 'The Discount Guide.' An entirely New Edition, carefully revised. Royal 8vo, strongly half-bound, 30*s.*

## *Comprehensive Discount Guide.*

THE DISCOUNT GUIDE: comprising several Series of Tables for the use of Merchants, Manufacturers, Ironmongers, and others, by which may be ascertained the exact profit arising from any mode of using Discounts, either in the Purchase or Sale of Goods, and the method of either Altering a Rate of Discount, or Advancing a Price, so as to produce, by one operation, a sum that will realise any required profit after allowing one or more Discounts: to which are added Tables of Profit or Advance from 1¼ to 90 per cent., Tables of Discount from 1¼ to 98¾ per cent., and Tables of Commission, &c., from ⅛ to 10 per cent. By HENRY HARBEN, Accountant, Author of "The Weight Calculator." New Edition, carefully Revised and Corrected. In a handsome demy 8vo. volume (544 pp.), strongly and elegantly half-bound, £1 5*s*.

## *Inwood's Tables, greatly enlarged and improved.*

TABLES FOR THE PURCHASING of ESTATES, Freehold, Copyhold, or Leasehold; Annuities, Advowsons, &c., and for the Renewing of Leases held under Cathedral Churches, Colleges, or other corporate bodies; for Terms of Years certain, and for Lives; also for Valuing Reversionary Estates, Deferred Annuities, Next Presentations, &c., together with Smart's Five Tables of Compound Interest, and an Extension of the same to Lower and Intermediate Rates. By WILLIAM INWOOD, Architect. The 20th edition, with considerable additions, and new and valuable Tables of Logarithms for the more Difficult Computations of the Interest of Money, Discount, Annuities, &c., by M. FÉDOR THOMAN, of the Société Crédit Mobilier of Paris. 12mo, 8*s*. cloth.

"Those interested in the purchase and sale of estates, and in the adjustment of compensation cases, as well as in transactions in annuities, life insurances, &c., will find the present edition of eminent service."—*Engineering.*

"'Inwood's Tables' still maintain a most enviable reputation. The new issue has been enriched by large additional contributions by M. Fédor Thoman, whose carefully arranged Tables cannot fail to be of the utmost utility."—*Mining Journal.*

## *Geometry for the Architect, Engineer, &c.*

PRACTICAL GEOMETRY, for the Architect, Engineer, and Mechanic; giving Rules for the Delineation and Application of various Geometrical Lines, Figures and Curves. By E. W. TARN, M.A., Architect, Author of "The Science of Building," &c. With 164 Illustrations. Demy 8vo. 12*s*. 6*d*., cloth.

"No book with the same objects in view has ever been published in which the clearness of the rules laid down and the illustrative diagrams have been so satisfactory."—*Scotsman.*

## *Compound Interest and Annuities.*

THEORY of COMPOUND INTEREST and ANNUITIES; with Tables of Logarithms for the more Difficult Computations of Interest, Discount, Annuities, &c., in all their Applications and Uses for Mercantile and State Purposes. With an elaborate Introduction. By FÉDOR THOMAN, of the Société Crédit Mobilier, Paris. 3rd Edition, carefully revised and corrected. 12mo, 4*s*. 6*d*., cl.

A very powerful work, and the Author has a very remarkable command of his subject."—*Professor A. de Morgan.*

"We recommend it to the notice of actuaries and accountants."—*Athenæum.*

⁂ The above bound with LINTERN'S MINERAL SURVEYOR. (See page 10.) Price 7*s*. 6*d*. cloth.

# SCIENCE AND ART.

## *Brewing.*

A HANDBOOK FOR YOUNG BREWERS. By Herbert Edwards Wright, B.A. (Trin. Coll. Camb.). Crown 8vo, 3*s.* 6*d.*, cloth. [*Just Published.*

"A thoroughly scientific treatise in popular language. It is evident that the author has mastered his subject in its scientific aspects."—*Morning Advertiser.*

"We would particularly recommend all teachers of the art to place a copy of it in every pupil's hands, and we feel sure its perusal will be attended with advantage."—*Brewer.*

## *The Military Sciences.*

AIDE-MÉMOIRE to the MILITARY SCIENCES. Framed from Contributions of Officers and others connected with the different Services. Originally edited by a Committee of the Corps of Royal Engineers. Second Edition, most carefully revised by an Officer of the Corps, with many additions; containing nearly 350 Engravings and many hundred Woodcuts. 3 vols. royal 8vo, extra cloth boards, and lettered, 4*l.* 10*s.*

"A compendious encyclopædia of military knowledge."—*Edinburgh Review.*

"The most comprehensive work of reference to the military and collateral sciences." —*Volunteer Service Gazette.*

## *Field Fortification.*

A TREATISE on FIELD FORTIFICATION, the ATTACK of FORTRESSES, MILITARY MINING, and RECONNOITRING. By Colonel I. S. Macaulay, late Professor of Fortification in the R. M. A., Woolwich. Sixth Edition, crown 8vo, cloth, with separate Atlas of 12 Plates, 12*s.* complete.

## *Field Fortification.*

HANDBOOK OF FIELD FORTIFICATION, intended for the Guidance of Officers preparing for Promotion, and especially adapted to the requirements of Beginners. By Major W. W. Knollys, F.R.G.S., 93rd Sutherland Highlanders, &c. With 163 Woodcuts. Crown 8vo, 3*s.* 6*d.* cloth.

## *Dye-Wares and Colours.*

THE MANUAL of COLOURS and DYE-WARES: their Properties, Applications, Valuation, Impurities, and Sophistications. For the Use of Dyers, Printers, Dry Salters, Brokers, &c. By J. W. Slater. Post 8vo, 7*s.* 6*d.*, cloth.

"A complete encyclopædia of the *materia tinctoria.* The information given respecting each article is full and precise, and the methods of determining the value of articles such as these, so liable to sophistication, are given with clearness, and are practical as well as valuable."—*Chemist and Druggist.*

## *Storms.*

STORMS: their Nature, Classification, and Laws, with the Means of Predicting them by their Embodiments, the Clouds. By William Blasius. With Coloured Plates and numerous Wood Engravings. Crown 8vo, 10*s.* 6*d.* cloth boards.

### *Light-Houses.*

EUROPEAN LIGHT-HOUSE SYSTEMS; being a Report of a Tour of Inspection made in 1873. By Major GEORGE H. ELLIOT, Corps of Engineers, U.S.A. Illustrated by 51 Engravings and 31 Woodcuts in the Text. 8vo, 21*s.* cloth.

### *Electricity.*

A MANUAL of ELECTRICITY; including Galvanism, Magnetism, Diamagnetism, Electro-Dynamics, Magno-Electricity, and the Electric Telegraph. By HENRY M. NOAD, Ph.D., F.C.S., Lecturer on Chemistry at St. George's Hospital. Fourth Edition, entirely rewritten. Illustrated by 500 Woodcuts. 8vo, 1*l.* 4*s.* cloth.

"The commendations already bestowed in the pages of the *Lancet* on the former editions of this work are more than ever merited by the present. The accounts given of electricity and galvanism are not only complete in a scientific sense, but, which is a rarer thing, are popular and interesting."—*Lancet.*

### *Text-Book of Electricity.*

THE STUDENT'S TEXT-BOOK OF ELECTRICITY. By HENRY M. NOAD, Ph.D., Lecturer on Chemistry at St. George's Hospital. New Edition, revised and enlarged, with additions on Telegraphy, the Telephone, Phonograph, &c., by G. E. PREECE, Esq., of the Telegraph Department, General Post Office, London. Upwards of 400 Illustrations.

[*Nearly ready.*

### *Rudimentary Magnetism.*

RUDIMENTARY MAGNETISM: being a concise exposition of the general principles of Magnetical Science, and the purposes to which it has been applied. By Sir W. SNOW HARRIS, F.R.S. New and enlarged Edition, with considerable additions by Dr. NOAD, Ph.D. With 165 Woodcuts. 12mo, cloth, 4*s.* 6*d.*

"As concise and lucid an exposition of the phenomena of magnetism as we believe it is possible to write."—*English Mechanic.*

"The best possible manual on the subject of magnetism."—*Mechanics' Magazine.*

### *Chemical Analysis.*

THE COMMERCIAL HANDBOOK of CHEMICAL ANALYSIS; or Practical Instructions for the determination of the Intrinsic or Commercial Value of Substances used in Manufactures, in Trades, and in the Arts. By A. NORMANDY, Author of "Practical Introduction to Rose's Chemistry," and Editor of Rose's "Treatise on Chemical Analysis." *New Edition.* Enlarged, and to a great extent re-written, by HENRY M. NOAD, Ph. D., F.R.S. With numerous Illustrations. Cr. 8vo, 12*s.* 6*d.* cloth.

"We recommend this book to the careful perusal of every one; it may be truly affirmed to be of universal interest, and we strongly recommend it to our readers as a guide, alike indispensable to the housewife as to the pharmaceutical practitioner."—*Medical Times.*

"Essential to the analysts appointed under the new Act. The most recent results are given, and the work is well edited and carefully written."—*Nature.*

### *Mollusca.*

A MANUAL OF THE MOLLUSCA; being a Treatise on Recent and Fossil Shells. By Dr. S. P. WOODWARD, A.L.S. With Appendix by RALPH TATE, A.L.S. F.G.S. With numerous Plates and 300 Woodcuts. 3rd Edition. Cr. 8vo, 7*s.* 6*d.* cloth.

## *Clocks, Watches, and Bells.*

RUDIMENTARY TREATISE on CLOCKS, and WATCHES, and BELLS. By Sir **EDMUND BECKETT**, Bart. (late E. B. Denison), LL.D., Q.C., F.R.A.S., Author of "Astronomy without Mathematics," &c. Sixth edition, thoroughly revised and enlarged, with numerous Illustrations. Limp cloth (No. 67, Weale's Series), 4*s.* 6*d.*; cloth boards, 5*s.* 6*d.*

"As a popular and practical treatise it is unapproached."—*English Mechanic.*

"The best work on the subject probably extant. The treatise on bells is undoubtedly the best in the language. To call it a rudimentary treatise is a misnomer, at least as respects clocks and bells. It is the most important work of its kind in English."—*Engineering.*

"The only modern treatise on clock-making."—*Horological Journal.*

"This admirable treatise on clocks, by the most able authority on such a subject, is completely perfect of its kind."—*Standard.*

## *Gold and Gold-Working.*

THE PRACTICAL GOLD-WORKER; or, The Goldsmith's and Jeweller's Instructor. The Art of Alloying, Melting, Reducing, Colouring, Collecting and Refining. The processes of Manipulation, Recovery of Waste, Chemical and Physical Properties of Gold, with a new System of Mixing its Alloys; Solders, Enamels, and other useful Rules and Recipes, &c. By **GEORGE E. GEE.** Crown 8vo, 7*s.* 6*d.*, cloth. [*Just Published.*

"A good, sound, technical educator, and will be generally accepted as an authority. It gives full particulars for mixing alloys and enamels, is essentially a book for the workshop, and exactly fulfils the purpose intended."—*Horological Journal*

"The best work yet printed on its subject for a reasonable price. We have no doubt that it will speedily become a standard book which few will care to be without."—*Jeweller and Metalworker.*

## *Silver and Silver Working.*

THE SILVERSMITH'S HANDBOOK, containing full Instructions for the Alloying and Working of Silver, including the different modes of refining and melting the metal, its solders, the preparation of imitation alloys, methods of manipulation, prevention of waste, instructions for improving and finishing the surface of the work, together with other useful information and memoranda. By **GEORGE E. GEE**, Jeweller, &c. Crown 8vo, with numerous illustrations, 7*s.* 6*d.*, cloth. [*Just Published.*

"This work is destined to take up as good a position in technical literature as the *Practical Goldworker*, a book which has passed through the ordeal of critical examination and business tests with great success."—*Jeweller and Metalworker.*

## *Science and Scripture.*

SCIENCE ELUCIDATIVE OF SCRIPTURE, AND NOT ANTAGONISTIC TO IT; being a Series of Essays on—1. Alleged Discrepancies; 2. The Theory of the Geologists and Figure of the Earth; 3. The Mosaic Cosmogony; 4. Miracles in general—Views of Hume and Powell; 5. The Miracle of Joshua—Views of Dr. Colenso: The Supernaturally Impossible; 6. The Age of the Fixed Stars—their Distances and Masses. By Professor **J. R. YOUNG.** Fcap. 8vo, 5*s.* cloth.

"Distinguished by the true spirit of scientific inquiry, by great knowledge, by keen logical ability, and by a style peculiarly clear, easy, and energetic."—*Nonconformist.*

## *Practical Philosophy.*

A SYNOPSIS of PRACTICAL PHILOSOPHY. By Rev. J. **CARR**, M.A., late Fellow of Trin. Coll., Camb. 2nd Ed. 18mo, 5*s.* cl.

# DR. LARDNER'S POPULAR WORKS.

## *Dr. Lardner's Museum of Science and Art.*

THE MUSEUM OF SCIENCE AND ART. Edited by DIONYSIUS LARDNER, D.C.L., formerly Professor of Natural Philosophy and Astronomy in University College, London. With upwards of 1200 Engravings on Wood. In 6 Double Volumes. Price £1 1*s*., in a new and elegant cloth binding, or handsomely bound in half morocco, 31*s*. 6*d*.

"The 'Museum of Science and Art' is the most valuable contribution that has ever been made to the Scientific Instruction of every class of society."—*Sir David Brewster in the North British Review.*

"Whether we consider the liberality and beauty of the illustrations, the charm of the writing, or the durable interest of the matter, we must express our belief that there is hardly to be found among the new books, one that would be welcomed by people of so many ages and classes as a valuable present."—*Examiner.*

⁂ *Separate books formed from the above, suitable for Workmen's Libraries, Science Classes, &c.*

COMMON THINGS EXPLAINED. Containing Air, Earth, Fire, Water, Time, Man, the Eye, Locomotion, Colour, Clocks and Watches, &c. 233 Illustrations, cloth gilt, 5*s*.

THE MICROSCOPE. Containing Optical Images, Magnifying Glasses, Origin and Description of the Microscope, Microscopic Objects, the Solar Microscope, Microscopic Drawing and Engraving, &c. 147 Illustrations, cloth gilt, 2*s*.

POPULAR GEOLOGY. Containing Earthquakes and Volcanoes, the Crust of the Earth, etc. 201 Illustrations, cloth gilt, 2*s*. 6*d*.

POPULAR PHYSICS. Containing Magnitude and Minuteness, the Atmosphere, Meteoric Stones, Popular Fallacies, Weather Prognostics, the Thermometer, the Barometer, Sound, &c. 85 Illustrations, cloth gilt, 2*s*. 6*d*.

STEAM AND ITS USES. Including the Steam Engine, the Locomotive, and Steam Navigation. 89 Illustrations, cloth gilt, 2*s*.

POPULAR ASTRONOMY. Containing How to Observe the Heavens. The Earth, Sun, Moon, Planets. Light, Comets, Eclipses, Astronomical Influences, &c. 182 Illustrations, 4*s*. 6*d*.

THE BEE AND WHITE ANTS: Their Manners and Habits. With Illustrations of Animal Instinct and Intelligence. 135 Illustrations, cloth gilt, 2*s*.

THE ELECTRIC TELEGRAPH POPULARISED. To render intelligible to all who can Read, irrespective of any previous Scientific Acquirements, the various forms of Telegraphy in Actual Operation. 100 Illustrations, cloth gilt, 1*s*. 6*d*.

## *Scientific Class-Books, by Dr. Lardner.*

NATURAL PHILOSOPHY FOR SCHOOLS. By DR. LARDNER. 328 Illustrations. Sixth Edition. 1 vol. 3*s*. 6*d*. cloth.

"Conveys, in clear and precise terms, general notions of all the principal divisions of Physical Science."—*British Quarterly Review.*

ANIMAL PHYSIOLOGY FOR SCHOOLS. By DR. LARDNER. With 190 Illustrations. Second Edition. 1 vol. 3*s*. 6*d*. cloth.

"Clearly written, well arranged, and excellently illustrated."—*Gardeners' Chronicle.*

# DR. LARDNER'S SCIENTIFIC WORKS.

## *Astronomy.*

THE HANDBOOK OF ASTRONOMY. 4th Edition. Edited by EDWIN DUNKIN, F.R.S., Rl. Observatory, Greenwich. With 38 plates and upwards of 100 Woodcuts. Cr. 8vo, 9*s.* 6*d.* cloth.

"Probably no other book contains the same amount of information in so compendious and well-arranged a form."—*Athenæum.*

## *Animal Physics.*

THE HANDBOOK OF ANIMAL PHYSICS. With 520 Illustrations. New edition, small 8vo, cloth, 7*s.* 6*d.* 732 pages.

"We have no hesitation in cordially recommending it."—*Educational Times.*

## *Electric Telegraph.*

THE ELECTRIC TELEGRAPH. New Edition. By E. B. BRIGHT, F.R.A.S. 140 Illustrations. Small 8vo, 2*s.* 6*d.* cloth.

"One of the most readable books extant on the Electric Telegraph."—*Eng. Mechanic.*

# LARDNER'S COURSE OF NATURAL PHILOSOPHY.

## *Mechanics.*

THE HANDBOOK OF MECHANICS. Enlarged and almost rewritten by BENJAMIN LOEWY, F.R.A.S. With 378 Illustrations. Post 8vo, 6*s.* cloth. [*Just Published.*

"The perspicuity of the original has been retained, and chapters which had become obsolete, have been replaced by others of more modern character. The explanations throughout are studiously popular, and care has been taken to show the application of the various branches of physics to the industrial arts, and to the practical business of life."—*Mining Journal.*

## *Heat.*

THE HANDBOOK OF HEAT. Edited and almost entirely Re-written by BENJAMIN LOEWY, F.R.A.S. etc. 117 Illustrations. Post 8vo, 6*s.* cloth. [*Just Published.*

"The style is always clear and precise, and conveys instruction without leaving any cloudiness or lurking doubts behind."—*Engineering.*

## *Hydrostatics and Pneumatics.*

THE HANDBOOK of HYDROSTATICS and PNEUMATICS. New Edition, Revised and Enlarged by BENJAMIN LOEWY, F.R.A.S. With 236 Illustrations. Post 8vo, 5*s.* cl.

"For those 'who desire to attain an accurate knowledge of physical science without the profound methods of mathematical investigation,' this work is not merely intended, but well adapted."—*Chemical News.*

## *Electricity, Magnetism, and Acoustics.*

THE HANDBOOK of ELECTRICITY, MAGNETISM, and ACOUSTICS. New Edition. Edited by GEO. CAREY FOSTER, B.A., F.C.S. With 400 Illustrations. Post 8vo, 5*s.* cloth.

"The book could not have been entrusted to any one better calculated to preserve the terse and lucid style of Lardner, while correcting his errors and bringing up his work to the present state of scientific knowledge."—*Popular Science Review.*

## *Optics.*

THE HANDBOOK OF OPTICS. New Edition. Edited by T. OLVER HARDING, B.A. 298 Illustrations. Post 8vo, 5*s.* cloth.

"Written by one of the ablest English scientific writers, beautifully and elaborately illustrated."—*Mechanic's Magazine.*

⁂ *The above* 5 *Vols. form* A COMPLETE COURSE OF NATURAL PHILOSOPHY.

## *Pictures and Painters.*

THE PICTURE AMATEUR'S HANDBOOK AND DICTIONARY OF PAINTERS: being a Guide for Visitors to Public and Private Picture Galleries, and for Art-Students, including an explanation of the various methods of Painting; Instructions for Cleaning, Re-Lining, and Restoring Oil Paintings; A Glossary of Terms; an Historical Sketch of the Principal Schools of Painting; and a Dictionary of Painters, giving the Copyists and Imitators of each Master. By PHILIPPE DARYL, B.A. Crown 8vo, 3*s.* 6*d.*, cloth. [*Just Published.*

"Useful as bringing together in a compendious form an almost complete biographical stock of information respecting the painters of the world."—*Mayfair.*

"The bulk of the book is occupied by a dictionary of painters which, considering its small compass, is really admirable; where only a few words are devoted to an artist, his speciality is well indicated; and the utility of a table of dates of painters in so portable a form is unquestionable. We cordially recommend the book."—*Builder.*

## *Popular Work on Painting.*

PAINTING POPULARLY EXPLAINED; with Historical Sketches of the Progress of the Art. By THOMAS JOHN GULLICK, Painter, and JOHN TIMBS, F.S.A. Fourth Edition, revised and enlarged. With Frontispiece and Vignette. In small 8vo, 6*s.* cloth.

⁂ *This Work has been adopted as a Prize-book in the Schools of Art at South Kensington.*

"Much may be learned, even by those who fancy they do not require to be taught, from the careful perusal of this unpretending but comprehensive treatise."—*Art Journal.*

"Contains a large amount of original matter, agreeably conveyed, and will be found of value, as well by the young artist seeking information as by the general reader."—*Builder.*

## *Grammar of Colouring.*

A GRAMMAR OF COLOURING, applied to Decorative Painting and the Arts. By GEORGE FIELD. New edition, enlarged and adapted to the use of the Ornamental Painter and Designer, by ELLIS A. DAVIDSON. With new Coloured Diagrams and numerous Engravings on Wood. 12mo, 3*s.* 6*d.* cloth boards.

"One of the most useful of student's books, and probably the best known of the few we have on the subject."—*Architect.*

"The book is a most useful *résumé* of the properties of pigments."—*Builder.*

## *Geology and Genesis Harmonised.*

THE TWIN RECORDS of CREATION; or, Geology and Genesis, their Perfect Harmony and Wonderful Concord. By G. W. VICTOR LE VAUX. With numerous Illus. Fcap. 8vo, 5*s.* cl.

"We can recommend Mr. Le Vaux as an able and interesting guide to a popular appreciation of geological science."—*Spectator.*

## *Geology, Physical and Historical.*

A CLASS-BOOK of GEOLOGY, PHYSICAL and HISTORICAL. With more than 250 Woodcuts. By RALPH TATE, A.L.S., F.G.S. 12mo, 5*s.*, cloth boards.

"The fulness of the matter has elevated the book into a manual."—*School Board Chronicle.*

## *Wood-Carving.*

INSTRUCTIONS in WOOD-CARVING, for Amateurs; with Hints on Design. By A LADY. In emblematic wrapper, handsomely printed, with Ten large Plates, 2*s.* 6*d.*

"The handicraft of the wood-carver, so well as a book can impart it, may be learnt from 'A Lady's' publication."—*Athenæum.*

## *Delamotte's Works on Illumination & Alphabets.*

A PRIMER OF THE ART OF ILLUMINATION; for the use of Beginners: with a Rudimentary Treatise on the Art, Practical Directions for its Exercise, and numerous Examples taken from Illuminated MSS., printed in Gold and Colours. By F. DELAMOTTE. Small 4to, 9*s.* Elegantly bound, cloth antique.

"A handy book, beautifully illustrated; the text of which is well written, and calculated to be useful. . . . The examples of ancient MSS. recommended to the student, which, with much good sense, the author chooses from collections accessible to all, are selected with judgment and knowledge, as well as taste."—*Athenæum.*

ORNAMENTAL ALPHABETS, ANCIENT and MEDIÆVAL; from the Eighth Century, with Numerals; including Gothic, Church-Text, large and small, German, Italian, Arabesque, Initials for Illumination, Monograms, Crosses, &c. &c., for the use of Architectural and Engineering Draughtsmen, Missal Painters, Masons, Decorative Painters, Lithographers, Engravers, Carvers, &c. &c. &c. Collected and engraved by F. DELAMOTTE, and printed in Colours. Royal 8vo, oblong, 4*s.* cloth.

"A well-known engraver and draughtsman has enrolled in this useful book the result of many years' study and research. For those who insert enamelled sentences round gilded chalices, who blazon shop legends over shop-doors, who letter church walls with pithy sentences from the Decalogue, this book will be useful."—*Athenæum.*

EXAMPLES OF MODERN ALPHABETS, PLAIN and ORNAMENTAL; including German, Old English, Saxon, Italic, Perspective, Greek, Hebrew, Court Hand, Engrossing, Tuscan, Riband, Gothic, Rustic, and Arabesque; with several Original Designs, and an Analysis of the Roman and Old English Alphabets, large and small, and Numerals, for the use of Draughtsmen, Surveyors, Masons, Decorative Painters, Lithographers, Engravers, Carvers, &c. Collected and engraved by F. DELAMOTTE, and printed in Colours. Royal 8vo, oblong, 4*s.* cloth.

"To artists of all classes, but more especially to architects and engravers, this very handsome book will be invaluable. There is comprised in it every possible shape into which the letters of the alphabet and numerals can be formed, and the talent which has been expended in the conception of the various plain and ornamental letters is wonderful."—*Standard.*

MEDIÆVAL ALPHABETS AND INITIALS FOR ILLUMINATORS. By F. DELAMOTTE, Illuminator, Designer, and Engraver on Wood. Containing 21 Plates, and Illuminated Title, printed in Gold and Colours. With an Introduction by J. WILLIS BROOKS. Small 4to, 6*s.* cloth gilt.

"A volume in which the letters of the alphabet come forth glorified in gilding and all the colours of the prism interwoven and intertwined and intermingled, sometimes with a sort of rainbow arabesque. A poem emblazoned in these characters would be only comparable to one of those delicious love letters symbolized in a bunch of flowers well selected and cleverly arranged."—*Sun.*

THE EMBROIDERER'S BOOK OF DESIGN; containing Initials, Emblems, Cyphers, Monograms, Ornamental Borders, Ecclesiastical Devices, Mediæval and Modern Alphabets, and National Emblems. Collected and engraved by F. DELAMOTTE, and printed in Colours. Oblong royal 8vo, 2*s.* 6*d.* in ornamental boards.

# AGRICULTURE, &c.

## *Youatt and Burn's Complete Grazier.*

THE COMPLETE GRAZIER, and FARMER'S and CATTLE-BREEDER'S ASSISTANT. A Compendium of Husbandry. By WILLIAM YOUATT, ESQ., V.S. 12th Edition, enlarged by ROBERT SCOTT BURN, Author of "The Lessons of My Farm," &c. One large 8vo volume, 860 pp. with 244 Illustrations. 1*l.* 1*s.* half-bd.

"The standard and text-book, with the farmer and grazier."—*Farmer's Magazine.*

"A treatise which will remain a standard work on the subject as long as British agriculture endures."—*Mark Lane Express.*

## *Spooner on Sheep.*

SHEEP; THE HISTORY, STRUCTURE, ECONOMY, AND DISEASES OF. By W. C. SPOONER, M.R.V.C., &c. Third Edition, considerably enlarged; with numerous fine engravings, including some specimens of New and Improved Breeds. Fcp. 8vo, 366 pp., 6*s.* cloth.

"The book is decidedly the best of the kind in our language."—*Scotsman.*

"Mr. Spooner has conferred upon the agricultural class a lasting benefit by embodying in this work the improvements made in sheep stock by such men as Humphreys, Rawlence, Howard, and others."—*Hampshire Advertiser.*

"The work should be in possession of every flock-master."—*Banbury Guardian.*

## *Scott Burn's System of Modern Farming.*

OUTLINES OF MODERN FARMING. By R. SCOTT BURN. Soils, Manures, and Crops—Farming and Farming Economy—Cattle, Sheep, and Horses—Management of the Dairy, Pigs, and Poultry—Utilisation of Town-Sewage, Irrigation, &c. New Edition. In 1 vol. 1250 pp., half-bound, profusely illustrated, 12*s.*

"There is sufficient stated within the limits of this treatise to prevent a farmer from going far wrong in any of his operations."—*Observer.*

## *Good Gardening.*

A PLAIN GUIDE TO GOOD GARDENING; or, How to Grow Vegetables, Fruits, and Flowers. With Practical Notes on Soils, Manures, Seeds, Planting, Laying-out of Gardens and Grounds, &c. By S. WOOD. Second Edition, with considerable Additions, &c., and numerous Illustrations. Cr. 8vo, 5*s.*, cloth.

"A very good book, and one to be highly recommended as a practical guide. The practical directions are excellent."—*Athenæum.*

"A thoroughly useful guidebook for the amateur gardener who may want to make his plot of land not merely pretty, but useful and profitable."—*Daily Telegraph.*

## *Profitable Gardening.*

MULTUM-IN-PARVO GARDENING; or, How to make One Acre of Land produce £620 a year, by the Cultivation of Fruits and Vegetables; also, How to Grow Flowers in Three Glass Houses, so as to realise £176 per annum clear Profit. By SAMUEL WOOD, Author of "Good Gardening," &c. 2nd Edition, revised. With Wood Engravings. Cr. 8vo, 2*s.*, cloth. [*Just Published.*

"We are bound to recommend it as not only suited to the case of the amateur and gentleman's gardener, but to the market grower."—*Gardener's Magazine.*

## *Horton's Underwood and Woodland Tables.*

TABLES FOR PLANTING and Valuing Underwood and Woodland. By R. HORTON. 12mo., 2*s.* bound.

### *Donaldson and Burn's Suburban Farming.*

SUBURBAN FARMING. A Treatise on the Laying Out and Cultivation of Farms, adapted to the produce of Milk, Butter and Cheese, Eggs, Poultry, and Pigs. By the late Professor JOHN DONALDSON. With considerable Additions, Illustrating the more Modern Practice by ROBERT SCOTT BURN. With numerous Illustrations. Crown 8vo, 6*s*., cloth. [*Just Published.*

"An admirable treatise on all matters connected with the laying-out and cultivation of dairy farms."—*Live Stock Journal.*

### *Ewart's Land Improver's Pocket-Book.*

THE LAND IMPROVER'S POCKET-BOOK OF FORMULÆ, TABLES, and MEMORANDA, required in any Computation relating to the Permanent Improvement of Landed Property. By JOHN EWART, Land Surveyor and Agricultural Engineer. Royal 32mo, oblong, leather, gilt edges, with elastic band, 4*s*.

"Admirably calculated to serve its purpose."—*Scotsman.*

"A compendious and handy little volume."—*Spectator.*

### *Hudson's Tables for Land Valuers.*

THE LAND VALUER'S BEST ASSISTANT: being Tables, on a very much improved Plan, for Calculating the Value of Estates. With Tables for reducing Scotch, Irish, and Provincial Customary Acres to Statute Measure; also, Tables of Square Measure, and of the Dimensions of an Acre by which the Contents of any Plot of Ground may be ascertained without the expense of a regular Survey; &c. By R. HUDSON, C.E. New Edition, royal 32mo, oblong, leather, gilt edges, with elastic band, 4*s*.

"Of incalculable value to country gentlemen and professional men."—*Farmer's Journal.*

### *Complete Agricultural Surveyor's Pocket-Book.*

THE LAND VALUER'S AND LAND IMPROVER'S COMPLETE POCKET-BOOK; consisting of the above two works bound together, leather, gilt edges, with strap, 7*s*. 6*d*.

☞ *The above forms an unequalled and most compendious Pocket Vade-mecum for the Land Agent and Agricultural Engineer.*

"We consider Hudson's book to be the best ready-reckoner on matters relating to the valuation of land and crops we have ever seen, and its combination with Mr. Ewart's work greatly enhances the value and usefulness of the latter-mentioned . . It is most useful as a manual for reference."—*North of England Farmer.*

### *The Management of Estates.*

LANDED ESTATES MANAGEMENT: Treating of the Varieties of Lands, Peculiarities of its Farms, Methods of Farming, the Setting-out of Farms and their Fields, Construction of Roads, Fences, Gates, and Farm Buildings, of Waste or Unproductive Lands, Irrigation, Drainage, Plantation, &c. By R. SCOTT BURN, Fcp. 8vo. numerous Illustrations, 3*s*. 6*d*.

### *Scott Burn's Introduction to Farming.*

THE LESSONS of MY FARM: a Book for Amateur Agriculturists, being an Introduction to Farm Practice, in the Culture of Crops, the Feeding of Cattle, Management of the Dairy, Poultry, Pigs, &c. By R. SCOTT BURN. With numerous Illus. Fcp. 6*s*. cl.

"A complete introduction to the whole round of farming practice."—*John Bull.*

## *"A Complete Epitome of the Laws of this Country."*

EVERY MAN'S OWN LAWYER; a Handy-Book of the Principles of Law and Equity. By A Barrister. 15th Edition, Revised to the end of last Session. Including a Summary of the Judicature Acts, and the principal Acts of the past Session, viz. —The Canal Boats' Act, The Destructive Insects' (or Colorado Beetle) Act, The Fisheries' (Oyster, Crab, and Lobster) Act, and the Fisheries' (Dynamite) Act, &c., &c. With Notes and References to the Authorities. Crown 8vo, price 6*s.* 8*d.* (saved at every consultation), strongly bound.

COMPRISING THE LAWS OF

Bankruptcy—Bills of Exchange—Contracts and Agreements—Copyright—Dower and Divorce—Elections and Registration—Insurance—Libel and Slander—Mortgages—Settlements—Stock Exchange Practice—Trade Marks and Patents—Trespass, Nuisances, etc.—Transfer of Land, etc.—Warranty—Wills and Agreements, etc. Also Law for Landlord and Tenant—Master and Servant—Workmen and Apprentices—Heirs, Devisees, and Legatees—Husband and Wife—Executors and Trustees—Guardian and Ward—Married Women and Infants—Partners and Agents—Lender and Borrower—Debtor and Creditor—Purchaser and Vendor—Companies and Associations—Friendly Societies—Clergymen, Churchwardens—Medical Practitioners, &c.—Bankers—Farmers—Contractors—Stock and Share Brokers—Sportsmen and Gamekeepers—Farriers and Horse-Dealers—Auctioneers, House-Agents—Innkeepers, &c.—Pawnbrokers—Surveyors—Railways and Carriers, &c. &c.

"No Englishman ought to be without this book."—*Engineer.*

"What it professes to be—a complete epitome of the laws of this country, thoroughly intelligible to non-professional readers."—*Bell's Life.*

## *Auctioneer's Assistant.*

THE APPRAISER, AUCTIONEER, BROKER, HOUSE AND ESTATE AGENT, AND VALUER'S POCKET ASSISTANT, for the Valuation for Purchase, Sale, or Renewal of Leases, Annuities, and Reversions, and of property generally; with Prices for Inventories, &c. By John Wheeler, Valuer, &c. Fourth Edition, enlarged, by C. Norris. Royal 32mo, cloth, 5*s.*

"A neat and concise book of reference, containing an admirable and clearly-arranged list of prices for inventories, and a very practical guide to determine the value of furniture, &c."—*Standard.*

## *Pawnbroker's Legal Guide.*

THE PAWNBROKER'S, FACTOR'S, and MERCHANT'S GUIDE to the LAW of LOANS and PLEDGES. By H. C. Folkard, Esq., Barrister-at-Law, Author of the "Law of Slander and Libel," &c. With Additions and Corrections to 1876. 12mo, cloth boards, 3*s.* 6*d.*

## *House Property.*

HANDBOOK OF HOUSE PROPERTY: a Popular and Practical Guide to the Purchase, Mortgage, Tenancy, and Compulsory Sale of Houses and Land; including the Law of Dilapidations and Fixtures; with Explanations and Examples of all kinds of Valuations, and useful Information and Advice on Building. By Edward Lance Tarbuck, Architect and Surveyor. 12mo, 5*s.* cloth boards.

"We are glad to be able to recommend it."—*Builder.*

"The advice is thoroughly practical."—*Law Journal.*

---

Bradbury, Agnew, & Co., Printers, Whitefriars, London.

# Weale's Rudimentary Series

PHILADELPHIA, 1876.
THE PRIZE MEDAL
Was awarded to the Publishers for
**Books: Rudimentary Scientific,**
**"WEALE'S SERIES," ETC.**

A NEW LIST OF

# WEALE'S SERIES

## RUDIMENTARY SCIENTIFIC, EDUCATIONAL, AND CLASSICAL.

LONDON, 1862.
THE PRIZE MEDAL
Was awarded to the Publishers of
**"WEALE'S SERIES."**

*These popular and cheap Series of Books, now comprising nearly Three Hundred distinct works in almost every department of Science, Art, and Education, are recommended to the notice of Engineers, Architects, Builders, Artisans, and Students generally, as well as to those interested in Workmen's Libraries, Free Libraries, Literary and Scientific Institutions, Colleges, Schools, Science Classes, &c., &c.*

*N.B.—In ordering from this List it is recommended, as a means of facilitating business and obviating error, to quote the numbers affixed to the volumes, as well as the titles and prices.*

⁂ **The books are bound in limp cloth, unless otherwise stated.**

## RUDIMENTARY SCIENTIFIC SERIES.

### ARCHITECTURE, BUILDING, ETC.

No.

16. *ARCHITECTURE—ORDERS*—The Orders and their Æsthetic Principles. By W. H. Leeds. Illustrated. 1s. 6d.

17. *ARCHITECTURE—STYLES*—The History and Description of the Styles of Architecture of Various Countries, from the Earliest to the Present Period. By T. Talbot Bury, F.R.I.B.A., &c. Illustrated. 2s.
⁂ Orders and Styles of Architecture, *in One Vol., 3s. 6d.*

18. *ARCHITECTURE—DESIGN*—The Principles of Design in Architecture, as deducible from Nature and exemplified in the Works of the Greek and Gothic Architects. By E. L. Garbett, Architect. Illustrated. 2s.

⁂ *The three preceding Works, in One handsome Vol., half bound, entitled* "Modern Architecture," *Price 6s.*

22. *THE ART OF BUILDING*, Rudiments of. General Principles of Construction, Materials used in Building, Strength and Use of Materials, Working Drawings, Specifications, and Estimates. By Edward Dobson, M.R.I.B.A., &c. Illustrated. 2s.

23. *BRICKS AND TILES*, Rudimentary Treatise on the Manufacture of; containing an Outline of the Principles of Brickmaking. By Edw. Dobson, M.R.I.B.A. With Additions by C. Tomlinson, F.R.S. Illustrated, 3s.

## Architecture, Building, etc., *continued.*

25. *MASONRY AND STONECUTTING*, Rudimentary Treatise on; in which the Principles of Masonic Projection and their application to the Construction of Curved Wing-Walls, Domes, Oblique Bridges, and Roman and Gothic Vaulting, are concisely explained. By Edward Dobson, M.R.I.B.A., &c. Illustrated with Plates and Diagrams. 2s. 6d.

44. *FOUNDATIONS AND CONCRETE WORKS*, a Rudimentary Treatise on; containing a Synopsis of the principal cases of Foundation Works, with the usual Modes of Treatment, and Practical Remarks on Footings, Planking, Sand, Concrete, Béton, Pile-driving, Caissons, and Cofferdams. By E. Dobson, M.R.I.B.A., &c. Fourth Edition, revised by George Dodd, C.E. Illustrated. 1s. 6d.

42. *COTTAGE BUILDING.* By C. Bruce Allen, Architect. Eleventh Edition, revised and enlarged. Numerous Illustrations. 1s. 6d.

45. *LIMES, CEMENTS, MORTARS, CONCRETES, MASTICS,* PLASTERING, &c. By G. R. Burnell, C.E. Ninth Edition. 1s. 6d.

57. *WARMING AND VENTILATION*, a Rudimentary Treatise on; being a concise Exposition of the General Principles of the Art of Warming and Ventilating Domestic and Public Buildings, Mines, Lighthouses, Ships, &c. By Charles Tomlinson, F.R.S., &c. Illustrated. 3s.

83**. *CONSTRUCTION OF DOOR LOCKS.* Compiled from the Papers of A. C. Hobbs, Esq., of New York, and Edited by Charles Tomlinson, F.R.S. To which is added, a Description of Fenby's Patent Locks, and a Note upon Iron Safes by Robert Mallet, M.I.C.E. Illus. 2s. 6d.

111. *ARCHES, PIERS, BUTTRESSES, &c.:* Experimental Essays on the Principles of Construction in; made with a view to their being useful to the Practical Builder. By William Bland. Illustrated. 1s. 6d.

116. *THE ACOUSTICS OF PUBLIC BUILDINGS;* or, The Principles of the Science of Sound applied to the purposes of the Architect and Builder. By T. Roger Smith, M.R.I.B.A., Architect. Illustrated. 1s. 6d.

124. *CONSTRUCTION OF ROOFS*, Treatise on the, as regards Carpentry and Joinery. Deduced from the Works of Robison, Price, and Tredgold. Illustrated. 1s. 6d.

127. *ARCHITECTURAL MODELLING IN PAPER*, the Art of. By T. A. Richardson, Architect. Illustrated. 1s. 6d.

128. *VITRUVIUS—THE ARCHITECTURE OF MARCUS VITRUVIUS POLLO.* In Ten Books. Translated from the Latin by Joseph Gwilt, F.S.A., F.R.A.S. With 23 Plates. 5s.

130. *GRECIAN ARCHITECTURE*, An Inquiry into the Principles of Beauty in; with a Historical View of the Rise and Progress of the Art in Greece. By the Earl of Aberdeen. 1s.

*** *The two Preceding Works in One handsome Vol., half bound, entitled* "Ancient Architecture." *Price* 6s.

132. *DWELLING-HOUSES*, a Rudimentary Treatise on the Erection of. By S. H. Brooks, Architect. New Edition, with Plates. 2s. 6d.

156. *QUANTITIES AND MEASUREMENTS*, How to Calculate and Take them in Bricklayers', Masons', Plasterers', Plumbers', Painters', Paperhangers', Gilders', Smiths', Carpenters', and Joiners' Work. By A. C. Beaton, Architect and Surveyor. New and Enlarged Edition. Illus. 1s. 6d.

175. *LOCKWOOD & CO.'S BUILDER'S AND CONTRACTOR'S* PRICE BOOK, for 1878, containing the latest Prices of all kinds of Builders' Materials and Labour, and of all Trades connected with Building: Lists of the Members of the Metropolitan Board of Works, of Districts, District Officers, and District Surveyors, and the Metropolitan Bye-laws. Edited by Francis T. W. Miller, Architect and Surveyor. 3s. 6d.

182. *CARPENTRY AND JOINERY*—The Elementary Principles of Carpentry. Chiefly composed from the Standard Work of Thomas Tredgold, C.E. With Additions from the Works of the most Recent Authorities, and a TREATISE ON JOINERY by E. Wyndham Tarn, M.A. Numerous Illustrations. 3s. 6d.

Architecture, Building, etc., *continued.*

182*. *CARPENTRY AND JOINERY. ATLAS* of 35 Plates to accompany the foregoing book. With Descriptive Letterpress. 4to. 6s.

187. *HINTS TO YOUNG ARCHITECTS.* By GEORGE WIGHTWICK. New, Revised, and enlarged Edition. By G. HUSKISSON GUILLAUME, Architect. With numerous Woodcuts. 3s. 6d.

188. *HOUSE PAINTING, GRAINING, MARBLING, AND SIGN WRITING:* A Practical Manual of. With 9 Coloured Plates of Woods and Marbles, and nearly 150 Wood Engravings. By ELLIS A. DAVIDSON. Second Edition, carefully revised, 5s. [*Just published.*

189. *THE RUDIMENTS OF PRACTICAL BRICKLAYING.* In Six Sections: General Principles; Arch Drawing, Cutting, and Setting; Pointing; Paving, Tiling, Materials; Slating and Plastering; Practical Geometry, Mensuration, &c. By ADAM HAMMOND. Illustrated. 1s. 6d.

191. *PLUMBING.* A Text-Book to the Practice of the Art or Craft of the Plumber. With Chapters upon House Drainage, embodying the latest Improvements. Containing about 300 Illustrations. By W. P. BUCHAN, Sanitary Engineer. 3s. [*Just published.*

192. *THE TIMBER IMPORTER'S, TIMBER MERCHANT'S,* and BUILDER'S STANDARD GUIDE; comprising copious and valuable Memoranda for the Retailer and Builder. By RICHARD E. GRANDY. Second Edition, Revised. 3s.

## CIVIL ENGINEERING, ETC.

13. *CIVIL ENGINEERING,* the Rudiments of; for the Use of Beginners, for Practical Engineers, and for the Army and Navy. By HENRY LAW, C.E. Including a Section on Hydraulic Engineering, by GEORGE R. BURNELL, C.E. 5th Edition, with Notes and Illustrations by ROBERT MALLET, A.M., F.R.S. Illustrated with Plates and Diagrams. 5s.

29. *THE DRAINAGE OF DISTRICTS AND LANDS.* By G. DRYSDALE DEMPSEY, C.E. New Edition, enlarged. Illustrated. 1s. 6d.

30. *THE DRAINAGE OF TOWNS AND BUILDINGS.* By G. DRYSDALE DEMPSEY, C.E. New Edition. Illustrated. 2s. 6d.
*** *With "Drainage of Districts and Lands," in One Vol., 3s. 6d.*

31. *WELL-DIGGING, BORING, AND PUMP-WORK.* By JOHN GEORGE SWINDELL, Assoc. R.I.B.A. New Edition, revised by G. R. BURNELL, C.E. Illustrated. 1s. 6d.

35. *THE BLASTING AND QUARRYING OF STONE,* for Building and other Purposes. With Remarks on the Blowing up of Bridges. By Gen. Sir JOHN BURGOYNE, Bart., K.C.B. Illustrated. 1s. 6d.

43. *TUBULAR AND OTHER IRON GIRDER BRIDGES.* Particularly describing the BRITANNIA and CONWAY TUBULAR BRIDGES. With a Sketch of Iron Bridges, and Illustrations of the Application of Malleable Iron to the Art of Bridge Building. By G. D. DEMPSEY, C.E. New Edition, with Illustrations. 1s. 6d.

62. *RAILWAY CONSTRUCTION,* Elementary and Practical Instruction on. By Sir MACDONALD STEPHENSON, C.E. New Edition, enlarged by EDWARD NUGENT, C.E. Plates and numerous Woodcuts. 3s.

80*. *EMBANKING LANDS FROM THE SEA,* the Practice of. Treated as a Means of Profitable Employment for Capital. With Examples and Particulars of actual Embankments, and also Practical Remarks on the Repair of old Sea Walls. By JOHN WIGGINS, F.G.S. New Edition, with Notes by ROBERT MALLET, F.R.S. 2s.

81. *WATER WORKS,* for the Supply of Cities and Towns. With a Description of the Principal Geological Formations of England as influencing Supplies of Water; and Details of Engines and Pumping Machinery for raising Water. By SAMUEL HUGHES, F.G.S., C.E. New Edition, revised and enlarged, with numerous Illustrations. 4s.

82**. *GAS WORKS,* and the Practice of Manufacturing and Distributing Coal Gas. By SAMUEL HUGHES, C.E. New Edition, revised by W. RICHARDS, C.E. Illustrated. 3s. 6d.

## Civil Engineering, etc., *continued.*

117. *SUBTERRANEOUS SURVEYING;* an Elementary and Practical Treatise on. By Thomas Fenwick. Also the Method of Conducting Subterraneous Surveys without the Use of the Magnetic Needle, and other modern Improvements. By Thomas Baker, C.E. Illustrated. 2s. 6d.

118. *CIVIL ENGINEERING IN NORTH AMERICA*, a Sketch of. By David Stevenson, F.R.S.E., &c. Plates and Diagrams. 3s.

121. *RIVERS AND TORRENTS.* With the Method of Regulating their Courses and Channels. By Professor Paul Frisi, F.R.S., of Milan. To which is added, AN ESSAY ON NAVIGABLE CANALS. Translated by Major-General John Garstin, of the Bengal Engineers. Plates. 2s. 6d.

197. *ROADS AND STREETS (THE CONSTRUCTION OF)*, in two Parts: I. The Art of Constructing Common Roads, by Henry Law, C.E., revised and condensed by D. Kinnear Clark, C.E.; II. Recent Practice in the Construction of Roads and Streets, including pavements of Stone, Wood, and Asphalte, by D. K. Clark, M.I.C.E., with numerous Illustrations. 4s. 6d. [*Just published.*

## MECHANICAL ENGINEERING, ETC.

33. *CRANES*, the Construction of, and other Machinery for Raising Heavy Bodies for the Erection of Buildings, and for Hoisting Goods. By Joseph Glynn, F.R.S., &c. Illustrated. 1s. 6d.

34. *THE STEAM ENGINE*, a Rudimentary Treatise on. By Dr. Lardner. Illustrated. 1s. 6d.

59. *STEAM BOILERS:* their Construction and Management. By R. Armstrong, C.E. Illustrated. 1s. 6d.

63. *AGRICULTURAL ENGINEERING:* Farm Buildings, Motive Power, Field Machines, Machinery, and Implements. By G. H. Andrews, C.E. Illustrated. 3s.

67. *CLOCKS, WATCHES, AND BELLS*, a Rudimentary Treatise on. By Sir Edmund Beckett (late Edmund Beckett Denison, LL.D., Q.C.). A new, Revised, and considerably Enlarged Edition (the 6th), with very numerous Illustrations. 4s. 6d. [*Just published.*

77*. *THE ECONOMY OF FUEL*, particularly with Reference to Reverbatory Furnaces for the Manufacture of Iron, and to Steam Boilers. By T. Symes Prideaux. 1s. 6d.

82. *THE POWER OF WATER*, as applied to drive Flour Mills, and to give motion to Turbines and other Hydrostatic Engines. By Joseph Glynn, F.R.S., &c. New Edition, Illustrated. 2s.

98. *PRACTICAL MECHANISM*, the Elements of; and Machine Tools. By T. Baker, C.E. With Remarks on Tools and Machinery, by J. Nasmyth, C.E. Plates. 2s. 6d.

114. *MACHINERY*, Elementary Principles of, in its Construction and Working. Illustrated by numerous Examples of Modern Machinery for different Branches of Manufacture. By C. D. Abel, C.E. 1s. 6d.

15. *ATLAS OF PLATES.* Illustrating the above Treatise. By C. D. Abel, C.E. 7s. 6d.

125. *THE COMBUSTION OF COAL AND THE PREVENTION* OF SMOKE, Chemically and Practically Considered. With an Appendix. By C. Wye Williams, A.I.C.E. Plates. 3s.

139. *THE STEAM ENGINE*, a Treatise on the Mathematical Theory of, with Rules at length, and Examples for the Use of Practical Men. By T. Baker, C.E. Illustrated. 1s. 6d.

162. *THE BRASS FOUNDER'S MANUAL;* Instructions for Modelling, Pattern-Making, Moulding, Turning, Filing, Burnishing, Bronzing, &c. With copious Receipts, numerous Tables, and Notes on Prime Costs and Estimates. By Walter Graham. Illustrated. 2s. 6d.

164. *MODERN WORKSHOP PRACTICE*, as applied to Marine, Land, and Locomotive Engines, Floating Docks, Dredging Machines, Bridges, Cranes, Ship-building, &c., &c. By J. G. Winton. Illustrated. 3s.

**Mechanical Engineering, etc.,** ***continued.***

165. *IRON AND HEAT*, exhibiting the Principles concerned in the Construction of Iron Beams, Pillars, and Bridge Girders, and the Action of Heat in the Smelting Furnace. By J. Armour, C.E. 2s. 6d.

166. *POWER IN MOTION:* Horse-Power, Motion, Toothed-Wheel Gearing, Long and Short Driving Bands, Angular Forces. By James Armour, C.E. With 73 Diagrams. 2s. 6d.

167. *THE APPLICATION OF IRON TO THE CONSTRUCTION* OF BRIDGES, GIRDERS, ROOFS, AND OTHER WORKS. By Francis Campin, C.E. Second Edition, revised and corrected. Numerous Woodcuts. 2s. 6d.

171. *THE WORKMAN'S MANUAL OF ENGINEERING* DRAWING. By John Maxton, Engineer, Instructor in Engineering Drawing, Royal Naval College, Greenwich. Third Edition. Illustrated with 7 Plates and nearly 350 Woodcuts. 3s. 6d.

190. *STEAM AND THE STEAM ENGINE*, Stationary and Portable. Being an extension of Mr. John Sewell's "Treatise on Steam." By D. Kinnear Clark, M.I.C.E., Author of "Railway Machinery," &c., &c. With numerous Illustrations. 3s. 6d.

---

## SHIPBUILDING, NAVIGATION, MARINE ENGINEERING, ETC.

51. *NAVAL ARCHITECTURE*, the Rudiments of; or, an Exposition of the Elementary Principles of the Science, and their Practical Application to Naval Construction. Compiled for the Use of Beginners. By James Peake, School of Naval Architecture, H.M. Dockyard, Portsmouth. Fourth Edition, corrected, with Plates and Diagrams. 3s. 6d.

53*. *SHIPS FOR OCEAN AND RIVER SERVICE*, Elementary and Practical Principles of the Construction of. By Hakon A. Sommerfeldt, Surveyor of the Royal Norwegian Navy. With an Appendix. 1s.

53**. *AN ATLAS OF ENGRAVINGS* to Illustrate the above. Twelve large folding plates. Royal 4to, cloth. 7s. 6d.

54. *MASTING, MAST-MAKING, AND RIGGING OF SHIPS*, Rudimentary Treatise on. Also Tables of Spars, Rigging, Blocks; Chain, Wire, and Hemp Ropes, &c., relative to every class of vessels. Together with an Appendix of Dimensions of Masts and Yards of the Royal Navy of Great Britain and Ireland. By Robert Kipping, N.A. Fourteenth Edition. Illustrated. 2s.

54*. *IRON SHIP-BUILDING*. With Practical Examples and Details for the Use of Ship Owners and Ship Builders. By John Grantham, Consulting Engineer and Naval Architect. 5th Edition, with Additions. 4s.

54**. *AN ATLAS OF FORTY PLATES* to Illustrate the above. Fifth Edition. Including the latest Examples, such as H.M. Steam Frigates "Warrior," "Hercules," "Bellerophon;" H.M. Troop Ship "Serapis," Iron Floating Dock, &c., &c. 4to, boards. 38s.

55. *THE SAILOR'S SEA BOOK:* a Rudimentary Treatise on Navigation. I. How to Keep the Log and Work it off. II. On Finding the Latitude and Longitude. By James Greenwood, B.A., of Jesus College, Cambridge. To which are added, Directions for Great Circle Sailing; an Essay on the Law of Storms and Variable Winds; and Explanations of Terms used in Ship-building. Ninth Edition, with several Engravings and Coloured Illustrations of the Flags of Maritime Nations. 2s.

80. *MARINE ENGINES, AND STEAM VESSELS*, a Treatise on. Together with Practical Remarks on the Screw and Propelling Power, as used in the Royal and Merchant Navy. By Robert Murray, C.E., Engineer-Surveyor to the Board of Trade. With a Glossary of Technical Terms, and their Equivalents in French, German, and Spanish. Fifth Edition, revised and enlarged. Illustrated. 3s.

### Shipbuilding, Navigation, etc., *continued.*

83*bis*. *THE FORMS OF SHIPS AND BOATS:* Hints, Experimentally Derived, on some of the Principles regulating Ship-building. By W. Bland. Sixth Edition, revised, with numerous Illustrations and Models. 1s. 6d.

99. *NAVIGATION AND NAUTICAL ASTRONOMY,* in Theory and Practice. With Attempts to facilitate the Finding of the Time and the Longitude at Sea. By J. R. Young, formerly Professor of Mathematics in Belfast College. Illustrated. 2s. 6d.

100*. *TABLES* intended to facilitate the Operations of Navigation and Nautical Astronomy, as an Accompaniment to the above Book. By J. R. Young. 1s. 6d.

106. *SHIPS' ANCHORS,* a Treatise on. By George Cotsell, N.A. Illustrated. 1s. 6d.

149. *SAILS AND SAIL-MAKING,* an Elementary Treatise on. With Draughting, and the Centre of Effort of the Sails. Also, Weights and Sizes of Ropes; Masting, Rigging, and Sails of Steam Vessels, &c., &c. Tenth Edition, enlarged, with an Appendix. By Robert Kipping, N.A., Sailmaker, Quayside, Newcastle. Illustrated. 2s. 6d.

155. *THE ENGINEER'S GUIDE TO THE ROYAL AND* MERCANTILE NAVIES. By a Practical Engineer. Revised by D. F. M'Carthy, late of the Ordnance Survey Office, Southampton. 3s.

## PHYSICAL SCIENCE, NATURAL PHILOSOPHY, ETC.

1. *CHEMISTRY,* for the Use of Beginners. By Professor George Fownes, F.R.S. With an Appendix, on the Application of Chemistry to Agriculture. 1s.

2. *NATURAL PHILOSOPHY,* Introduction to the Study of; for the Use of Beginners. By C. Tomlinson, Lecturer on Natural Science in King's College School, London. Woodcuts. 1s. 6d.

4. *MINERALOGY,* Rudiments of; a concise View of the Properties of Minerals. By A. Ramsay, Jun. Woodcuts and Steel Plates. 3s.

6. *MECHANICS,* Rudimentary Treatise on; being a concise Exposition of the General Principles of Mechanical Science, and their Applications. By Charles Tomlinson, Lecturer on Natural Science in King's College School, London. Illustrated. 1s. 6d.

7. *ELECTRICITY;* showing the General Principles of Electrical Science, and the purposes to which it has been applied. By Sir W. Snow Harris, F.R.S., &c. With considerable Additions by R. Sabine, C.E., F.S.A. Woodcuts. 1s. 6d.

7*. *GALVANISM,* Rudimentary Treatise on, and the General Principles of Animal and Voltaic Electricity. By Sir W. Snow Harris. New Edition, revised, with considerable Additions, by Robert Sabine, C.E., F.S.A. Woodcuts. 1s. 6d.

8. *MAGNETISM;* being a concise Exposition of the General Principles of Magnetical Science, and the Purposes to which it has been applied. By Sir W. Snow Harris. New Edition, revised and enlarged by H. M. Noad, Ph.D., Vice-President of the Chemical Society, Author of "A Manual of Electricity," &c., &c. With 165 Woodcuts. 3s. 6d.

1. *THE ELECTRIC TELEGRAPH;* its History and Progress; with Descriptions of some of the Apparatus. By R. Sabine, C.E., F.S.A., &c. Woodcuts. 3s.

12. *PNEUMATICS,* for the Use of Beginners. By Charles Tomlinson. Illustrated. 1s. 6d.

72. *MANUAL OF THE MOLLUSCA;* a Treatise on Recent and Fossil Shells. By Dr. S. P. Woodward, A.L.S. With Appendix by Ralph Tate, A.L.S., F.G.S. With numerous Plates and 300 Woodcuts, 6s. 6d. Cloth boards, 7s. 6d.

**Physical Science, Natural Philosophy, etc., *continued.***

79**. *PHOTOGRAPHY*, Popular Treatise on; with a Description of the Stereoscope, &c. Translated from the French of D. Van Monckhoven, by W. H. Thornthwaite, Ph.D. Woodcuts. 1s. 6d.

96. *ASTRONOMY.* By the Rev. R. Main, M.A., F.R.S., &c. New and enlarged Edition, with an Appendix on "Spectrum Analysis." Woodcuts. 1s. 6d.

97. *STATICS AND DYNAMICS*, the Principles and Practice of; embracing also a clear development of Hydrostatics, Hydrodynamics, and Central Forces. By T. Baker, C.E. 1s. 6d.

138. *TELEGRAPH*, Handbook of the; a Manual of Telegraphy, Telegraph Clerks' Remembrancer, and Guide to Candidates for Employment in the Telegraph Service. By R. Bond. Fourth Edition, revised and enlarged: to which is appended, QUESTIONS on MAGNETISM, ELECTRICITY, and PRACTICAL TELEGRAPHY, for the Use of Students, by W. McGregor, First Assistant Superintendent, Indian Gov. Telegraphs. Woodcuts. 3s.

143. *EXPERIMENTAL ESSAYS.* By Charles Tomlinson. I. On the Motions of Camphor on Water. II. On the Motion of Camphor towards the Light. III. History of the Modern Theory of Dew. Woodcuts. 1s.

173. *PHYSICAL GEOLOGY*, partly based on Major-General Portlock's "Rudiments of Geology." By Ralph Tate, A.L.S., &c. Numerous Woodcuts. 2s.

174. *HISTORICAL GEOLOGY*, partly based on Major-General Portlock's "Rudiments." By Ralph Tate, A.L.S., &c. Woodcuts. 2s. 6d.

173 & 174. *RUDIMENTARY TREATISE ON GEOLOGY*, Physical and Historical. Partly based on Major-General Portlock's "Rudiments of Geology." By Ralph Tate, A.L.S., F.G.S., &c., &c. Numerous Illustrations. In One Volume. 4s. 6d.

183. & 184. *ANIMAL PHYSICS*, Handbook of. By Dionysius Lardner, D.C.L., formerly Professor of Natural Philosophy and Astronomy in University College, London. With 520 Illustrations. In One Volume, cloth boards. 7s. 6d.

⁂ *Sold also in Two Parts, as follows:—*

183. Animal Physics. By Dr. Lardner. Part I., Chapter I—VII. 4s.
184. Animal Physics. By Dr. Lardner. Part II. Chapter VIII—XVIII. 3s.

## MINING, METALLURGY, ETC.

117. *SUBTERRANEOUS SURVEYING*, Elementary and Practical Treatise on, with and without the Magnetic Needle. By Thomas Fenwick, Surveyor of Mines, and Thomas Baker, C.E. Illustrated. 2s. 6d.

133. *METALLURGY OF COPPER;* an Introduction to the Methods of Seeking, Mining, and Assaying Copper, and Manufacturing its Alloys. By Robert H. Lamborn, Ph.D. Woodcuts. 2s. 6d.

134. *METALLURGY OF SILVER AND LEAD.* A Description of the Ores; their Assay and Treatment, and valuable Constituents. By Dr. R. H. Lamborn. Woodcuts. 2s

135. *ELECTRO-METALLURGY;* Practically Treated. By Alexander Watt, F.R.S.S.A. New Edition, enlarged. Woodcuts. 2s. 6d.

172. *MINING TOOLS*, Manual of. For the Use of Mine Managers, Agents, Students, &c. Comprising Observations on the Materials from, and Processes by, which they are manufactured; their Special Uses, Applications, Qualities, and Efficiency. By William Morgans, Lecturer on Mining at the Bristol School of Mines. 2s. 6d.

172*. *MINING TOOLS, ATLAS* of Engravings to Illustrate the above, containing 235 Illustrations of Mining Tools. drawn to Scale. 4to 4s. 6d.

**Mining, Metallurgy, etc.,** *continued.*

176. *METALLURGY OF IRON*, a Treatise on the. Containing History of Iron Manufacture, Methods of Assay, and Analyses of Iron Ores, Processes of Manufacture of Iron and Steel, &c. By H. Bauerman, F.G.S. Fourth Edition, enlarged, with numerous Illustrations. 4s. 6d.

180. *COAL AND COAL MINING:* A Rudimentary Treatise on. By Warington W. Smyth, M.A., F.R.S., &c., Chief Inspector of the Mines of the Crown and of the Duchy of Cornwall. New Edition, revised and corrected. With numerous Illustrations. 3s. 6d.

195. *THE MINERAL SURVEYOR AND VALUER'S COM-*PLETE GUIDE, with new Traverse Tables; and Descriptions of Improved Instruments; also the Correct Principles of Laying out and Valuing Mineral Properties. By William Lintern, Mining and Civil Engineer. With four Plates of Diagrams, Plans, &c. 3s. 6d. [*Now Ready.*

## EMIGRATION.

154. *GENERAL HINTS TO EMIGRANTS.* Containing Notices of the various Fields for Emigration. With Hints on Preparation for Emigrating, Outfits, &c., &c. With Directions and Recipes useful to the Emigrant. With a Map of the World. 2s.

157. *THE EMIGRANT'S GUIDE TO NATAL.* By Robert James Mann, F.R.A.S., F.M.S. Second Edition, carefully corrected to the present Date. Map. 2s.

159. *THE EMIGRANT'S GUIDE TO AUSTRALIA, New South Wales, Western Australia, South Australia, Victoria, and Queensland.* By the Rev. James Baird, B.A. Map. 2s. 6d.

160. *THE EMIGRANT'S GUIDE TO TASMANIA and NEW ZEALAND.* By the Rev. James Baird, B.A. With a Map. 2s.

159 & 160. *THE EMIGRANT'S GUIDE TO AUSTRALASIA.* By the Rev. J. Baird, B.A. Comprising the above two volumes, cloth boards. 5s.

## AGRICULTURE.

29. *THE DRAINAGE OF DISTRICTS AND LANDS.* By G. Drysdale Dempsey, C.E. Illustrated. 1s. 6d.

⁂ *With "Drainage of Towns and Buildings," in One Vol., 3s. 6d.*

63. *AGRICULTURAL ENGINEERING:* Farm Buildings, Motive Powers and Machinery of the Steading, Field Machines, and Implements. By G. H. Andrews, C.E. Illustrated. 3s.

66. *CLAY LANDS AND LOAMY SOILS.* By Professor Donaldson. 1s.

131. *MILLER'S, MERCHANT'S, AND FARMER'S READY* RECKONER, for ascertaining at sight the value of any quantity of Corn, from One Bushel to One Hundred Quarters, at any given price, from £1 to £5 per Qr. With approximate values of Millstones, Millwork, &c. 1s.

140. *SOILS, MANURES, AND CROPS.* (Vol. 1. Outlines of Modern Farming.) By R. Scott Burn. Woodcuts. 2s.

141. *FARMING AND FARMING ECONOMY*, Notes, Historical and Practical, on. (Vol. 2. Outlines of Modern Farming.) By R. Scott Burn. Woodcuts. 3s.

142. *STOCK; CATTLE, SHEEP, AND HORSES.* (Vol. 3. Outlines of Modern Farming.) By R. Scott Burn. Woodcuts. 2s. 6d.

145. *DAIRY, PIGS, AND POULTRY*, Management of the. By R. Scott Burn. With Notes on the Diseases of Stock. (Vol. 4. Outlines of Modern Farming.) Woodcuts. 2s.

146. *UTILIZATION OF SEWAGE, IRRIGATION, AND* RECLAMATION OF WASTE LAND. (Vol. 5. Outlines of Modern Farming.) By R. Scott Burn. Woodcuts. 2s. 6d.

⁂ Nos. 140-1-2-5-6, in One Vol., handsomely half-bound, entitled "Outlines of Modern Farming." By Robert Scott Burn. Price 12s.

177. *FRUIT TREES*, The Scientific and Profitable Culture of. From the French of Du Breuil, Revised by Geo. Glenny. 187 Woodcuts. 3s. 6d

## FINE ARTS.

20. *PERSPECTIVE FOR BEGINNERS.* Adapted to Young Students and Amateurs in Architecture, Painting, &c. By George Pyne, Artist. Woodcuts. 2s.

40 & 41. *GLASS STAINING;* or, Painting on Glass, The Art of. Comprising Directions for Preparing the Pigments and Fluxes, laying them upon the Glass, and Firing or Burning in the Colours. From the German of Dr. Gessert. To which is added, an Appendix on The Art of Enamelling, &c., with The Art of Painting on Glass. From the German of Emanuel Otto Fromberg. In One Volume. 2s. 6d.

69. *MUSIC,* A Rudimentary and Practical Treatise on. With numerous Examples. By Charles Child Spencer. 2s. 6d.

71. *PIANOFORTE,* The Art of Playing the. With numerous Exercises and Lessons. Written and Selected from the Best Masters, by Charles Child Spencer. 1s. 6d.

181. *PAINTING POPULARLY EXPLAINED,* including Fresco, Oil, Mosaic, Water Colour, Water-Glass, Tempera, Encaustic, Miniature, Painting on Ivory, Vellum, Pottery, Enamel, Glass, &c. With Historical Sketches of the Progress of the Art by Thomas John Gullick, assisted by John Timbs, F.S.A. Third Edition, revised and enlarged, with Frontispiece and Vignette. 5s.

186. *A GRAMMAR OF COLOURING,* applied to Decorative Painting and the Arts. By George Field. New Edition, enlarged and adapted to the Use of the Ornamental Painter and Designer. By Ellis A. Davidson, Author of "Drawing for Carpenters," &c. With two new Coloured Diagrams and numerous Engravings on Wood. 2s. 6d.

---

## ARITHMETIC, GEOMETRY, MATHEMATICS, ETC.

32. *MATHEMATICAL INSTRUMENTS,* a Treatise on; in which their Construction and the Methods of Testing, Adjusting, and Using them are concisely Explained. By J. F. Heather, M.A., of the Royal Military Academy, Woolwich. Original Edition, in 1 vol., Illustrated. 1s. 6d.

⁂ *In ordering the above, be careful to say, "Original Edition," or give the number in the Series* (32) *to distinguish it from the Enlarged Edition in* 3 *vols.* (*Nos.* 168-9-70.)

60. *LAND AND ENGINEERING SURVEYING,* a Treatise on; with all the Modern Improvements. Arranged for the Use of Schools and Private Students; also for Practical Land Surveyors and Engineers. By T. Baker, C.E. New Edition, revised by Edward Nugent, C.E. Illustrated with Plates and Diagrams. 2s.

61*. *READY RECKONER FOR THE ADMEASUREMENT OF* LAND. By Abraham Arman, Schoolmaster, Thurleigh, Beds. To which is added a Table, showing the Price of Work, from 2s. 6d. to £1 per acre, and Tables for the Valuation of Land, from 1s. to £1,000 per acre, and from one pole to two thousand acres in extent, &c., &c. 1s. 6d.

76. *DESCRIPTIVE GEOMETRY,* an Elementary Treatise on; with a Theory of Shadows and of Perspective, extracted from the French of G. Monge. To which is added, a description of the Principles and Practice of Isometrical Projection; the whole being intended as an introduction to the Application of Descriptive Geometry to various branches of the Arts. By J. F. Heather, M.A. Illustrated with 14 Plates. 2s.

178. *PRACTICAL PLANE GEOMETRY:* giving the Simplest Modes of Constructing Figures contained in one Plane and Geometrical Construction of the Ground. By J. F. Heather, M.A. With 215 Woodcuts. 2s.

9. *PROJECTION:* Orthographic, Topographic, and Perspective: giving the various Modes of Delineating Solid Forms by Constructions on a Single Plane Surface. By J. F. Heather, M.A. [*In preparation.*

⁂ *The above three volumes will form a* Complete Elementary Course of Mathematical Drawing.

## Arithmetic, Geometry, Mathematics, etc., *continued.*

83. *COMMERCIAL BOOK-KEEPING.* With Commercial Phrases and Forms in English, French, Italian, and German. By James Haddon, M.A., Arithmetical Master of King's College School, London. 1s.

84. *ARITHMETIC,* a Rudimentary Treatise on: with full Explanations of its Theoretical Principles, and numerous Examples for Practice. For the Use of Schools and for Self-Instruction. By J. R. Young, late Professor of Mathematics in Belfast College. New Edition, with Index. 1s. 6d.

84*. A Key to the above, containing Solutions in full to the Exercises, together with Comments, Explanations, and Improved Processes, for the Use of Teachers and Unassisted Learners. By J. R. Young. 1s. 6d.

85. *EQUATIONAL ARITHMETIC,* applied to Questions of Interest,
85*. Annuities, Life Assurance, and General Commerce; with various Tables by which all Calculations may be greatly facilitated. By W. Hipsley. 2s.

86. *ALGEBRA,* the Elements of. By James Haddon, M.A., Second Mathematical Master of King's College School. With Appendix, containing miscellaneous Investigations, and a Collection of Problems in various parts of Algebra. 2s.

86*. A Key and Companion to the above Book, forming an extensive repository of Solved Examples and Problems in Illustration of the various Expedients necessary in Algebraical Operations. Especially adapted for Self-Instruction. By J. R. Young. 1s. 6d.

88. *EUCLID,* The Elements of: with many additional Propositions
89. and Explanatory Notes: to which is prefixed, an Introductory Essay on Logic. By Henry Law, C.E. 2s. 6d.

⁂ *Sold also separately, viz.:—*

88. Euclid, The First Three Books. By Henry Law, C.E. 1s.
89. Euclid, Books 4, 5, 6, 11, 12. By Henry Law, C.E. 1s. 6d.

90. *ANALYTICAL GEOMETRY AND CONIC SECTIONS,* a Rudimentary Treatise on. By James Hann, late Mathematical Master of King's College School, London. A New Edition, re-written and enlarged by J. R. Young, formerly Professor of Mathematics at Belfast College. 2s.

91. *PLANE TRIGONOMETRY,* the Elements of. By James Hann, formerly Mathematical Master of King's College, London. 1s.

92. *SPHERICAL TRIGONOMETRY,* the Elements of. By James Hann. Revised by Charles H. Dowling, C.E. 1s.

⁂ *Or with "The Elements of Plane Trigonometry," in One Volume, 2s.*

93. *MENSURATION AND MEASURING,* for Students and Practical Use. With the Mensuration and Levelling of Land for the Purposes of Modern Engineering. By T. Baker, C.E. New Edition, with Corrections and Additions by E. Nugent, C.E. Illustrated. 1s. 6d.

94. *LOGARITHMS,* a Treatise on; with Mathematical Tables for facilitating Astronomical, Nautical, Trigonometrical, and Logarithmic Calculations; Tables of Natural Sines and Tangents and Natural Cosines. By Henry Law, C.E. Illustrated. 2s. 6d.

101*. *MEASURES, WEIGHTS, AND MONEYS OF ALL NATIONS,* and an Analysis of the Christian, Hebrew, and Mahometan Calendars. By W. S. B. Woolhouse, F.R.A.S., &c. 1s. 6d.

102. *INTEGRAL CALCULUS,* Rudimentary Treatise on the. By Homersham Cox, B.A. Illustrated. 1s.

103. *INTEGRAL CALCULUS,* Examples on the. By James Hann, late of King's College, London. Illustrated. 1s.

101. *DIFFERENTIAL CALCULUS,* Examples of the. By W. S. B. Woolhouse, F.R.A.S., &c. 1s. 6d.

104. *DIFFERENTIAL CALCULUS,* Examples and Solutions of the. By James Haddon, M.A. 1s.

## Arithmetic, Geometry, Mathematics, etc., *continued.*

105. *MNEMONICAL LESSONS.*—Geometry, Algebra, and Trigonometry, in Easy Mnemonical Lessons. By the Rev. Thomas Penyngton Kirkman, M.A. 1s. 6d.

136. *ARITHMETIC,* Rudimentary, for the Use of Schools and Self-Instruction. By James Haddon, M.A. Revised by Abraham Arman. 1s. 6d.

137. A Key to Haddon's Rudimentary Arithmetic. By A. Arman. 1s. 6d.

147. *ARITHMETIC,* Stepping-Stone to; being a Complete Course of Exercises in the First Four Rules (Simple and Compound), on an entirely new principle. For the Use of Elementary Schools of every Grade. Intended as an Introduction to the more extended works on Arithmetic. By Abraham Arman. 1s.

148. A Key to Stepping-Stone to Arithmetic. By A. Arman. 1s.

158. *THE SLIDE RULE, AND HOW TO USE IT;* containing full, easy, and simple Instructions to perform all Business Calculations with unexampled rapidity and accuracy. By Charles Hoare, C.E. With a Slide Rule in tuck of cover. 3s.

168. *DRAWING AND MEASURING INSTRUMENTS.* Including—I. Instruments employed in Geometrical and Mechanical Drawing, and in the Construction, Copying, and Measurement of Maps and Plans. II. Instruments used for the purposes of Accurate Measurement, and for Arithmetical Computations. By J. F. Heather, M.A., late of the Royal Military Academy, Woolwich, Author of "Descriptive Geometry," &c., &c. Illustrated. 1s. 6d.

169. *OPTICAL INSTRUMENTS.* Including (more especially) Telescopes, Microscopes, and Apparatus for producing copies of Maps and Plans by Photography. By J. F. Heather, M.A. Illustrated. 1s. 6d.

170. *SURVEYING AND ASTRONOMICAL INSTRUMENTS.* Including—I. Instruments Used for Determining the Geometrical Features of a portion of Ground. II. Instruments Employed in Astronomical Observations. By J. F. Heather, M.A. Illustrated. 1s. 6d.

⁂ *The above three volumes form an enlargement of the Author's original work, "Mathematical Instruments: their Construction, Adjustment, Testing, and Use," the Eleventh Edition of which is on sale, price 1s. 6d.* (*See No. 32 in the Series.*)

168. }
169. } *MATHEMATICAL INSTRUMENTS.* By J. F. Heather, M.A. Enlarged Edition, for the most part entirely re-written. The 3 Parts as above, in One thick Volume. With numerous Illustrations. 4s. 6d.
170. }

185. *THE COMPLETE MEASURER;* setting forth the Measurement of Boards, Glass, &c., &c.; Unequal-sided, Square-sided, Octagonal-sided, Round Timber and Stone, and Standing Timber. With a Table showing the solidity of hewn or eight-sided timber, or of any octagonal-sided column. Compiled for the accommodation of Timber-growers, Merchants, and Surveyors, Stonemasons, Architects, and others. By Richard Horton. Third Edition, with valuable additions. 4s.

196. *THEORY OF COMPOUND INTEREST AND ANNUITIES;* with Tables of Logarithms for the more Difficult Computations of Interest, Discount, Annuities, &c. By Fédor Thoman, of the Société Crédit Mobilier, Paris. 4s. [*Now ready.*

## LEGAL TREATISES.

50. *THE LAW OF CONTRACTS FOR WORKS AND SERVICES.* By David Gibbons. Third Edition, revised and considerably enlarged. 3s. [*Just published.*

151. *A HANDY BOOK ON THE LAW OF FRIENDLY, INDUSTRIAL & PROVIDENT BUILDING & LOAN SOCIETIES.* With copious Notes. By Nathaniel White, of H.M. Civil Service. 1s.

163. *THE LAW OF PATENTS FOR INVENTIONS;* and on the Protection of Designs and Trade Marks. By F. W. Campin, Barrister-at-Law. 2s.

## MISCELLANEOUS VOLUMES.

36. *A DICTIONARY OF TERMS used in ARCHITECTURE, BUILDING, ENGINEERING, MINING, METALLURGY, ARCHÆOLOGY, the FINE ARTS, &c.* By John Weale. Fifth Edition. Revised by Robert Hunt, F.R.S., Keeper of Mining Records. Numerous Illustrations. 5s.

112. *MANUAL OF DOMESTIC MEDICINE.* By R. Gooding, B.A., M.B. Intended as a Family Guide in all Cases of Accident and Emergency. 2s.

112*. *MANAGEMENT OF HEALTH.* A Manual of Home and Personal Hygiene. By the Rev. James Baird, B.A. 1s.

113. *FIELD ARTILLERY ON SERVICE.* By Taubert, Captain Prussian Artillery. Translated by Lieut.-Col. H. H. Maxwell. 1s. 6d.

113*. *SWORDS, AND OTHER ARMS.* By Col. Marey. Translated by Col. H. H. Maxwell. With Plates. 1s.

150. *LOGIC,* Pure and Applied. By S. H. Emmens. Third Edition. 1s. 6d.

152. *PRACTICAL HINTS FOR INVESTING MONEY.* With an Explanation of the Mode of Transacting Business on the Stock Exchange. By Francis Playford, Sworn Broker. 1s. 6d.

153. *SELECTIONS FROM LOCKE'S ESSAYS ON THE HUMAN UNDERSTANDING.* With Notes by S. H. Emmens. 2s.

193. *HANDBOOK OF FIELD FORTIFICATION,* intended for the Guidance of Officers Preparing for Promotion, and especially adapted to the requirements of Beginners. By Major W. W. KNOLLYS, F.R.G.S., 93rd Sutherland Highlanders, &c. With 163 Woodcuts. 3s.

194. *THE HOUSE MANAGER:* Being a Guide to Housekeeping. Practical Cookery, Pickling and Preserving, Household Work, Dairy Management, the Table and Dessert, Cellarage of Wines, Home-brewing and Wine-making, the Boudoir and Dressing-room, Travelling, Stable Economy, Gardening Operations, &c. By An Old Housekeeper. 3s. 6d.

# EDUCATIONAL AND CLASSICAL SERIES.

## HISTORY.

1. **England, Outlines of the History of;** more especially with reference to the Origin and Progress of the English Constitution. A Text Book for Schools and Colleges. By William Douglas Hamilton, F.S.A., of Her Majesty's Public Record Office. Fourth Edition, revised. Maps and Woodcuts. 5s.; cloth boards, 6s.

5. **Greece, Outlines of the History of;** in connection with the Rise of the Arts and Civilization in Europe. By W. Douglas Hamilton, of University College, London, and Edward Levien, M.A., of Balliol College, Oxford. 2s. 6d.; cloth boards, 3s. 6d.

7. **Rome, Outlines of the History of:** from the Earliest Period to the Christian Era and the Commencement of the Decline of the Empire. By Edward Levien, of Balliol College, Oxford. Map, 2s. 6d.; cl. bds. 3s. 6d.

9. **Chronology of History, Art, Literature, and Progress,** from the Creation of the World to the Conclusion of the Franco-German War. The Continuation by W. D. Hamilton, F.S.A., of Her Majesty's Record Office. 3s.; cloth boards, 3s. 6d.

50. **Dates and Events in English History,** for the use of Candidates in Public and Private Examinations. By the Rev. E. Rand. 1s.

## ENGLISH LANGUAGE AND MISCELLANEOUS.

11. **Grammar of the English Tongue,** Spoken and Written. With an Introduction to the Study of Comparative Philology. By HYDE CLARKE, D.C.L. Third Edition. 1s.

11*. **Philology:** Handbook of the Comparative Philology of English, Anglo-Saxon, Frisian, Flemish or Dutch, Low or Platt Dutch, High Dutch or German, Danish, Swedish, Icelandic, Latin, Italian, French, Spanish, and Portuguese Tongues. By HYDE CLARKE, D.C.L. 1s.

12. **Dictionary of the English Language,** as Spoken and Written. Containing above 100,000 Words. By HYDE CLARKE, D.C.L. 3s. 6d.; cloth boards, 4s. 6d.; complete with the GRAMMAR, cloth bds., 5s. 6d.

48. **Composition and Punctuation,** familiarly Explained for those who have neglected the Study of Grammar. By JUSTIN BRENAN. 16th Edition. 1s.

49. **Derivative Spelling-Book:** Giving the Origin of Every Word from the Greek, Latin, Saxon, German, Teutonic, Dutch, French, Spanish, and other Languages; with their present Acceptation and Pronunciation. By J. ROWBOTHAM, F.R.A.S. Improved Edition. 1s. 6d.

51. **The Art of Extempore Speaking:** Hints for the Pulpit, the Senate, and the Bar. By M. BAUTAIN, Vicar-General and Professor at the Sorbonne. Translated from the French. Sixth Edition, carefully corrected. 2s. 6d.

52. **Mining and Quarrying,** with the Sciences connected therewith. First Book of, for Schools. By J. H. COLLINS, F.G.S., Lecturer to the Miners' Association of Cornwall and Devon. 1s.

53. **Places and Facts in Political and Physical Geography,** for Candidates in Public and Private Examinations. By the Rev. EDGAR RAND, B.A. 1s.

54. **Analytical Chemistry,** Qualitative and Quantitative, a Course of. To which is prefixed, a Brief Treatise upon Modern Chemical Nomenclature and Notation. By WM. W. PINK, Practical Chemist, &c., and GEORGE E. WEBSTER, Lecturer on Metallurgy and the Applied Sciences, Nottingham. 2s.

## THE SCHOOL MANAGERS' SERIES OF READING BOOKS,

Adapted to the Requirements of the New Code. Edited by the Rev. A. R. GRANT, Rector of Hitcham, and Honorary Canon of Ely; formerly H.M. Inspector of Schools.

INTRODUCTORY PRIMER, 3*d*.

| | *s.* | *d.* | | *s.* | *d.* |
|---|---|---|---|---|---|
| FIRST STANDARD | 0 | 6 | FOURTH STANDARD | 1 | 2 |
| SECOND ,, | 0 | 10 | FIFTH ,, | 1 | 6 |
| THIRD ,, | 1 | 0 | SIXTH ,, | 1 | 6 |

LESSONS FROM THE BIBLE. Part I. Old Testament. 1s.

LESSONS FROM THE BIBLE. Part II. New Testament, to which is added THE GEOGRAPHY OF THE BIBLE, for very young Children. By Rev. C. THORNTON FORSTER. 1s. 2d. *‚* Or the Two Parts in One Volume. 2s.

## FRENCH.

24. **French Grammar.** With Complete and Concise Rules on the Genders of French Nouns. By G. L. STRAUSS, Ph.D. 1s.

25. **French-English Dictionary.** Comprising a large number of New Terms used in Engineering, Mining, on Railways, &c. By ALFRED ELWES. 1s. 6d.

26. **English-French Dictionary.** By ALFRED ELWES. 2s.

25,26. **French Dictionary** (as above). Complete, in One Vol., 3s.; cloth boards, 3s. 6d. *‚* Or with the GRAMMAR, cloth boards, 4s. 6d.

French, *continued.*

47. **French and English Phrase Book:** containing Introductory Lessons, with Translations, for the convenience of Students; several Vocabularies of Words, a Collection of suitable Phrases, and Easy Familiar Dialogues. 1s.

## GERMAN.

39. **German Grammar.** Adapted for English Students, from Heyse's Theoretical and Practical Grammar, by Dr. G. L. STRAUSS. 1s.

40. **German Reader:** A Series of Extracts, carefully culled from the most approved Authors of Germany; with Notes, Philological and Explanatory. By G. L. STRAUSS, Ph.D. 1s.

41. **German Triglot Dictionary.** By NICHOLAS ESTERHAZY, S. A. HAMILTON. Part I. English-German-French. 1s.

42. **German Triglot Dictionary.** Part II. German-French-English. 1s.

43. **German Triglot Dictionary.** Part III. French-German-English. 1s.

41-43. **German Triglot Dictionary** (as above), in One Vol., 3s.; cloth boards, 4s. *** Or with the GERMAN GRAMMAR, cloth boards, 5s.

## ITALIAN.

27. **Italian Grammar,** arranged in Twenty Lessons, with a Course of Exercises. By ALFRED ELWES. 1s.

28. **Italian Triglot Dictionary,** wherein the Genders of all the Italian and French Nouns are carefully noted down. By ALFRED ELWES. Vol. 1. Italian-English-French. 2s.

30. **Italian Triglot Dictionary.** By A. ELWES. Vol. 2. English-French-Italian. 2s.

32. **Italian Triglot Dictionary.** By ALFRED ELWES. Vol. 3. French-Italian-English. 2s.

28,30, 32. **Italian Triglot Dictionary** (as above). In One Vol., 6s. cloth boards, 7s. 6d. *** Or with the ITALIAN GRAMMAR, cloth bds., 8s. 6d.

## SPANISH AND PORTUGUESE.

34. **Spanish Grammar,** in a Simple and Practical Form. With a Course of Exercises. By ALFRED ELWES. 1s. 6d.

35. **Spanish-English and English-Spanish Dictionary.** Including a large number of Technical Terms used in Mining, Engineering, &c., with the proper Accents and the Gender of every Noun. By ALFRED ELWES. 4s.; cloth boards, 5s. *** Or with the GRAMMAR, cloth boards, 6s.

55. **Portuguese Grammar,** in a Simple and Practical Form. With a Course of Exercises. By ALFRED ELWES, Author of "A Spanish Grammar," &c. 1s. 6d. [*Just published.*

## HEBREW.

46*. **Hebrew Grammar** By Dr. BRESSLAU. 1s. 6d.

44. **Hebrew and English Dictionary,** Biblical and Rabbinical; containing the Hebrew and Chaldee Roots of the Old Testament Post-Rabbinical Writings. By Dr. BRESSLAU. 6s. *** Or with the GRAMMAR, 7s.

46. **English and Hebrew Dictionary.** By Dr. BRESSLAU. 3s.

44,46. 46*. **Hebrew Dictionary** (as above), in Two Vols., complete, with the GRAMMAR, cloth boards, 12s.

## LATIN.

19. **Latin Grammar.** Containing the Inflections and Elementary Principles of Translation and Construction. By the Rev. THOMAS GOODWIN, M.A., Head Master of the Greenwich Proprietary School. 1s.

20. **Latin-English Dictionary.** Compiled from the best Authorities. By the Rev. THOMAS GOODWIN, M.A. 2s.

22. **English-Latin Dictionary;** together with an Appendix of French and Italian Words which have their origin from the Latin. By the Rev. THOMAS GOODWIN, M.A. 1s. 6d.

20,22. **Latin Dictionary** (as above). Complete in One Vol., 3s. 6d.; cloth boards, 4s. 6d. ⁂ Or with the GRAMMAR, cloth boards, 5s. 6d.

### LATIN CLASSICS. With Explanatory Notes in English.

1. **Latin Delectus.** Containing Extracts from Classical Authors, with Genealogical Vocabularies and Explanatory Notes, by HENRY YOUNG, lately Second Master of the Royal Grammar School, Guildford. 1s.

2. **Cæsaris** Commentarii de Bello Gallico. Notes, and a Geographical Register for the Use of Schools, by H. YOUNG. 2s.

12. **Ciceronis** Oratio pro Sexto Roscio Amerino. Edited, with an Introduction, Analysis, and Notes Explanatory and Critical, by the Rev. JAMES DAVIES, M.A. 1s.

14. **Ciceronis** Cato Major, Lælius, Brutus, sive de Senectute, de Amicitia, de Claris Oratoribus Dialogi. With Notes by W. BROWNRIGG SMITH, M.A., F.R.G.S. 2s.

3. **Cornelius Nepos.** With Notes. Intended for the Use of Schools. By H. YOUNG. 1s.

6. **Horace;** Odes, Epode, and Carmen Sæculare. Notes by H. YOUNG. 1s. 6d.

7. **Horace;** Satires, Epistles, and Ars Poetica. Notes by W. BROWNRIGG SMITH, M.A., F.R.G.S. 1s. 6d.

21. **Juvenalis** Satiræ. With Prolegomena and Notes by T. H. S. ESCOTT, B.A., Lecturer on Logic at King's College, London. 1s. 6d.

16. **Livy:** History of Rome. Notes by H. YOUNG and W. B. SMITH, M.A. Part 1. Books i., ii., 1s. 6d.

16*. ——— Part 2. Books iii., iv., v., 1s. 6d.

17. ——— Part 3 Books xxi., xxii., 1s. 6d.

8. **Sallustii** Crispi Catalina et Bellum Jugurthinum. Notes Critical and Explanatory, by W. M. DONNE, B.A., Trinity College, Cambridge. 1s. 6d.

10. **Terentii** Adelphi, Hecyra, Phormio. Edited, with Notes, Critical and Explanatory, by the Rev. JAMES DAVIES, M.A. 2s.

9. **Terentii** Andria et Heautontimorumenos. With Notes, Critical and Explanatory, by the Rev. JAMES DAVIES, M.A. 1s. 6d.

11. **Terentii** Eunuchus, Comœdia. Edited, with Notes, by the Rev. JAMES DAVIES, M.A. 1s. 6d. Or the Adelphi, Andria, and Eunuchus, 3 vols. in 1, cloth boards, 6s.

4. **Virgilii** Maronis Bucolica et Georgica. With Notes on the Bucolics by W. RUSHTON, M.A., and on the Georgics by H. YOUNG. 1s. 6d.

5. **Virgilii** Maronis Æneis. Notes, Critical and Explanatory, by H. YOUNG. 2s.

19. **Latin Verse Selections,** from Catullus, Tibullus, Propertius, and Ovid. Notes by W. B. DONNE, M.A., Trinity College, Cambridge. 2s.

20. **Latin Prose Selections,** from Varro, Columella, Vitruvius, Seneca, Quintilian, Florus, Velleius Paterculus, Valerius Maximus Suetonius, Apuleius, &c. Notes by W. B. DONNE, M.A. 2s.

☞ *Other Volumes are in Preparation.*

## GREEK.

14. **Greek Grammar,** in accordance with the Principles and Philological Researches of the most eminent Scholars of our own day. By HANS CLAUDE HAMILTON. 1s. 6d.

15,17. **Greek Lexicon.** Containing all the Words in General Use, with their Significations, Inflections, and Doubtful Quantities. By HENRY R. HAMILTON. Vol. 1. Greek-English, 2s.; Vol. 2. English-Greek, 2s. Or the Two Vols. in One, 4s.: cloth boards, 5s.

14,15, 17. **Greek Lexicon** (as above). Complete, with the GRAMMAR, in One Vol., cloth boards, 6s.

### GREEK CLASSICS. With Explanatory Notes in English.

1. **Greek Delectus.** Containing Extracts from Classical Authors, with Genealogical Vocabularies and Explanatory Notes, by H. YOUNG. New Edition, with an improved and enlarged Supplementary Vocabulary, by JOHN HUTCHISON, M.A., of the High School, Glasgow. 1s.

30. **Æschylus:** Prometheus Vinctus: The Prometheus Bound. From the Text of DINDORF. Edited, with English Notes, Critical and Explanatory, by the Rev. JAMES DAVIES, M.A. 1s.

32. **Æschylus:** Septem Contra Thebes: The Seven against Thebes. From the Text of DINDORF. Edited, with English Notes, Critical and Explanatory, by the Rev. JAMES DAVIES, M.A. 1s.

40. **Aristophanes:** Acharnians. Chiefly from the Text of C. H. WEISE. With Notes, by C. S. T. TOWNSHEND, M.A. 1s. 6d.

26. **Euripides:** Alcestis. Chiefly from the Text of DINDORF. With Notes, Critical and Explanatory, by JOHN MILNER, B.A. 1s.

23. **Euripides:** Hecuba and Medea. Chiefly from the Text of DINDORF. With Notes, Critical and Explanatory, by W. BROWNRIGG SMITH, M.A., F.R.G.S. 1s. 6d.

4-17. **Herodotus,** The History of, chiefly after the Text of GAISFORD. With Preliminary Observations and Appendices, and Notes, Critical and Explanatory, by T. H. L. LEARY, M.A., D.C.L.

- Part 1. Books i., ii. (The Clio and Euterpe), 2s.
- Part 2. Books iii., iv. (The Thalia and Melpomene), 2s.
- Part 3. Books v.-vii. (The Terpsichore, Erato, and Polymnia), 2s.
- Part 4. Books viii., ix. (The Urania and Calliope) and Index, 1s. 6d.

5-12. **Homer,** The Works of. According to the Text of BAEUMLEIN. With Notes, Critical and Explanatory, drawn from the best and latest Authorities, with Preliminary Observations and Appendices, by T. H. L. LEARY, M.A., D.C.L.

| | | |
|---|---|---|
| THE ILIAD: | Part 1. Books i. to vi., 1s. 6d. | Part 3. Books xiii. to xviii., 1s. 6d. |
| | Part 2. Books vii. to xii., 1s. 6d. | Part 4. Books xix. to xxiv., 1s. 6d. |
| THE ODYSSEY: | Part 1. Books i. to vi., 1s. 6d. | Part 3. Books xiii. to xviii., 1s. 6d. |
| | Part 2. Books vii. to xii., 1s. 6d. | Part 4. Books xix. to xxiv., and Hymns, 2s. |

4. **Lucian's Select Dialogues.** The Text carefully revised, with Grammatical and Explanatory Notes, by H. YOUNG. 1s.

13. **Plato's Dialogues:** The Apology of Socrates, the Crito, and the Phædo. From the Text of C. F. HERMANN. Edited with Notes, Critical and Explanatory, by the Rev. JAMES DAVIES, M.A. 2s.

18. **Sophocles:** Œdipus Tyrannus. Notes by H. YOUNG. 1s.

20. **Sophocles:** Antigone. From the Text of DINDORF. Notes, Critical and Explanatory, by the Rev. JOHN MILNER, B.A. 2s.

41. **Thucydides:** History of the Peloponnesian War. Notes by H. YOUNG. Book 1. 1s.

2, 3. **Xenophon's Anabasis;** or, The Retreat of the Ten Thousand. Notes and a Geographical Register, by H. YOUNG. Part 1. Books i. to iii., 1s. Part 2. Books iv. to vii., 1s.

42. **Xenophon's Panegyric on Agesilaus.** Notes and Introduction by LL. F. W. JEWITT. 1s. 6d.

☞ *Other Volumes are in Preparation.*

UNIVERSITY OF MICHIGAN
3 9015 02105 7719